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LECTURES

ON THE

SCIENCE

OF

ASTRONOMY,

EXPLANATORY AND DEMONSTRATIVE,

Which were First Delivered,

AT VARIOUS PLACES IN NEW-JERSEY,

IN THE YEAR 1820.

WITH A

GLOSSARY AND SUPPLEMENT.

BY DAVID YOUNG.

MORRIS-TOWN,
PRINTED FOR THE AUTHOR;
By J. Mann.

1821.

District of New-Jersey, to wit:

L.S.

BE it remembered, that on the fourth day of December, in the forty sixth year of the Independence of the United States of America, DAVID YOUNG, of the said District, hath deposited in this office, the title of a Book, the right whereof he claims as Author, in the words following, to wit:

"Lectures on the Science of Astronomy, explan-
"atory and demonstrative, which were first deliv-
"ered at various places in New-Jersey, in the year
"one thousand eight hundred and twenty, with a
"Glossary and Supplement. By David Young."

In conformity to an Act of the Congress of the United States, entitled "An act for the encouragement of learning, by securing the copies of Maps, Charts and Books to the Authors and Proprietors of such copies, during the times therein mentioned;" and also to the act entitled an "Act supplementary to the Act, entitled an Act for the encouragement of learning, by securing the copies of Maps, Charts and Books to the authors and proprietors of such copies, during the times therein mentioned, and extending the benefits thereof to the arts of designing, etching and engraving historical and other prints.

WM. PENNINGTON, *Clerk of the*
District of New-Jersey.

PREFACE.

FOR several years past almost every person, among my numerous acquaintances, has manifested a disposition to inquire into the Sublime mysteries of Astronomy. The curiosity of people seems to have been sufficiently excited to fill their mouths with interrogations on every occasion when I have been present. Questions of such a nature could not, however, be answered in a very trice. Most generally, neither I nor the inquirers have had sufficient leisure to attend to the subjects.

The primary object in view therefore in writing these Lectures, was that these reiterated questions might receive their final answers. I chose to deliver them before classes formed for the purpose, in order thereby to abridge my labour in answering the questions to every one. To promote, as far as I was able, the knowledge of Astronomy among my countrymen, was also a desirable object.

When requested, by many of the audience, to publish the Lectures, I could not long refuse; because I supposed their publication might more effectually and more extensively promote the accomplishment of my wishes. Frequent perusals will be more advantageous than a solitary hearing.

If Piety and Religion may be promoted by the publication of small tracts; why may not the knowledge of Astronomy and the cause of Science in general, be advanced by similar means?

I presume that no person will expect to find these Lectures printed verbatim as they were delivered. Revision is always proper, and on the present occasion appeared so necessary that I have not been altogether negligent in that respect. But after all I shall be very far from challenging the critic to point out defects.

D. Y.

Hanover, November 9, 1821.

GLOSSARY.

ALTITUDE, the distance above the horizon measured on an azimuth circle.

Amplitude, the distance of a celestial object, when rising, from the east point of the horizon, and when setting, from the west point of it. It is either north or south.

Angle, the mutual inclination of two lines meeting in a point; a corner.

Antipodes, [a local term] the inhabitants of the opposite point of the earth's surface.

Aphelion, that point of a planet's orbit which is at the greatest distance from the sun. Plural, Aphelia.

Apogee, that point of the moon's orbit which is at the greatest distance from the earth. This term is not unfrequently applied to the sun, to signify that point in which he is farthest from the earth.

Arc, a segment of a circle.

Area, any open surface.

Aspect, a term applied to signify the situation or apparent distance of any two celestial bodies in the zodiac from each other.

Asteroids, star-like bodies, a term of recent invention, and applied to four small bodies lately discovered in the Solar System, between the orbits of Mars and Jupiter.

Axis, a straight line, real or imaginary, passing through the centre of a body, on which it may revolve. Plural, Axes.

Azimuth, the angle formed by the meridian and the vertical circle passing through the centre of any celestial object.

Bissextile, a year consisting of 366 days, by adding a day to the month of February every fourth year.

Centrifugal, flying off from the centre.

Centripetal, inclining towards the centre.

Circle, a line of uniform curvature, returning into itself, or ending where it began; being in every part equally distant from the centre of the area which it includes.

Circumference, the length of a circular line.

Coma, a faint light surrounding the nucleus, or solid body, of a comet.

Concave, hollow, opposed to convex.

Concavity, the internal surface of a hollow body.

Conjunction, that aspect in which two celestial bodies in the zodiac have the same longitude.

Constellation; this term is applied to any assemblage or cluster of neighbouring stars, which astronomers have classed together under one general name.

Convex, rising in a spherical form, opposite to concave.

Convexity, protuberance in a spherical form.

Cycle, any certain period of time in which all the circumstances, to which the cycle has reference, regularly return. The most noted chronological cycles are the four following.

1. The Solar Cycle, a period of 28 years, after which the days of the months will fall on the same days of the week as in the same year of a former cycle;

2. The Metonic or Lunar Cycle, a period of 19 years, after which the change, full and other phases of the moon, will return to the same days of the months as in the same year of a former cycle.

3. The Roman Indiction, a period of 15 years, instituted by Constantine in A. D. 312, and observed among the Romans as a period for collecting certain taxes. It was afterwards introduced into chronology.

4. The Julian period, a cycle of 7980 years (arising from the multiplication of the three former periods together) after which the years of the Solar Cycle, Lunar Cycle and Indiction, will all be the same as in the same year of a former cycle of this period; provided the course of nature shall continue uninterrupted. The commencement of this period is of antemundane date, for no later than the year B. C. 4713, could the other three cycles begin together.

Data, such things as are known or granted, from which to reason.

Declination, that arc of the meridian passing through a celestial body, which is intercepted between it and the equator.

Degree, [in mathematics] the 360th part of a circle; the integer by which the quantity of an angle is expressed.

Density, hardness, closeness, compactness.

Diameter, a line passing through the centre of the area of a circle, or through the centre of a globe, from side to side.

Digit, a twelfth part of the apparent diameter of the sun or moon.

Disk, the face of the sun, moon, or other planet, as it appears to the eye,

Eccentricity, deviation from the centre, deviation from a circle.

Ecliptic, the sun's apparent annual path through the heavens, the plane of the earth's orbit.

Ellipsis, an oval figure, a figure approaching to a circle.

Elongation, the angular distance of a planet from the sun.

Epact, the excess of the Solar year above the Lunar; or it is (in the new style) the moon's age at the beginning of the year.

Equation of time, the difference between apparent and mean Solar time.

Equator, a great circle of the sphere, dividing it into northern and southern hemispheres.

Focus, either of the two points where pins, or pegs, are fixed, in describing an ellipsis. Plural, foci.

Friction, the resistance arising from the rubbing of one thing against another.

Galaxy, a nebulous tract in the heavens; the Milky Way.

Geocentric, having the earth for a centre; having the same centre as the earth.

Globe, a sphere, a ball, a round body having all parts of its surface equally distant from its centre.

Glossary, a dictionary of obscure or antiquated words.

Golden Number, the year of the Lunar Cycle.

Heliocentric, having the sun for a centre.

Hemisphere, half a sphere; half a globe.

Horizon, the line or circle that terminates our view; the circle which appears to divide the heavens and the earth.

Inclination [in the mathematics] a tendency of one line, or one plane, towards another.

Latitude [in the heavens] is reckoned north and south from the ecliptic, as that on the earth is from the equator.

Longitude is reckoned eastward from the first point of Aries quite round the heavens to the same point again.

Maximum, the utmost extent, the highest degree.

Nadir, the point, in the heavens, which is directly under our feet. A local term.

Nebulæ, whitish spots in the heavens, caused by vast clusters of very distant stars.

Nodes, points where the planetary orbits intersect the ecliptic. The point in which a planet passes the ecliptic from south to north is called the *ascending* node, and that where it passes it from north to south is the *descending* node.

Nucleus, the body, or solid part, of a comet.

Oblate, flatted at the poles.

Occultation, the time that a planet or star is hidden by the interposition of the moon.

Opaque, obscure, dark, not transparent.

Opposition, that aspect in which the difference of longitude of two bodies is 180 degrees, or half a circle.

Orbit, the path in which a planet moves round the sun; a circular path.

Oval, a figure approaching to a circle; an ellipsis.

Parallax, the difference between the true place of a celestial body, seen from the centre of the earth, and its apparent place seen from a spectator on the earth's surface. It is always equal to the angle at the body subtended by a semidiameter of the earth terminating in the place of the observer.

Parallel, extended in the same direction, always preserving the same distance.

Penumbra, a faint or imperfect shade, observed in Solar eclipses, and occasioned by a partial interception of the sun's light.

Perigee, that point in the moon's orbit which is nearest the earth. This term is also frequently used to signify that point in which the sun is nearest the earth.

Perihelium, that point of a planet's orbit which is nearest to the sun. Plural, perihelia.

Phenomenon, any appearance in the works of nature. Plural, phenomena.

Plane, an even surface, a level area.

Quartile, that aspect in which two bodies have 90 degrees difference of longitude.

Radius, the semidiameter of a circle. Plural, radii.

Refraction, the variation of the rays of light from their direct course on entering obliquely into a different medium.

Rotundity, roundness, sphericity.

Satellite, a small planet revolving round a larger one; a secondary planet.

Secant, a right line drawn from the centre of a circle, touching one extremity of an arc and continued until it meet the tangent which touches the other extremity of the arc.

Segment, a part cut off from a circle by a line not passing through its centre; also a part cut off from a globe, in like manner, by a plane not passing through its centre.

Sextile, that aspect where the difference of longitude of two bodies is 60 degrees.

Sine, a line (within a circle) dropped from one extremity of an arc, and falling at right angles on the radius which touches the other extremity of the arc.

Sphere, a round body; a globe. [See globe.]

Sphericity, roundness, rotundity.

Spheroid, a body approaching to the form of a sphere.

Syzygy; this term is applied both to signify the conjunction and the opposition of a planet and the sun. It is however used chiefly in relation to the sun and moon.

Tangent, a right line which touches a curve in one point, and is perpendicular to the radius of curvature. The tangent of an arc meets the secant of the same arc, and terminates at the junction.

Transit, the passage of one of the heavenly bodies over another; the passage of Mercury or Venus across the sun's disk.

Trine, that aspect where two bodies are at the distance of 120 degrees from each other.

Zenith, that point in the heavens which is directly over our heads. A local term.

Zodiac, an imaginary belt or girdle surrounding the heavens, extending so wide on both sides of the ecliptic as to include the orbits of all the planets.

A TABLE

Showing the Length of a Degree of Longitude at every Degree of Latitude, from the Equator to the Poles, in English miles.

Lat.	Eng. Miles	Lat.	Eng. Miles	Lat.	Eng. Miles	Lat.	Eng. Miles	Lat.	Eng. Miles
0	69.50	18	66.10	36	56.23	54	40.85	72	21.48
1	69.49	19	65.71	37	55.51	55	39.86	73	20.32
2	69.46	20	65.31	38	54.77	56	38.86	74	19.16
3	69.40	21	64.88	39	54.01	57	37.85	75	17.99
4	69.33	22	64.44	40	53.24	58	36.83	76	16.81
5	69.24	23	63·98	41	52.45	59	35.80	77	15.63
6	69.12	24	63.49	42	51.65	60	34.75	78	14.45
7	68.98	25	62.99	43	50.83	61	33.69	79	13.26
8	68.82	26	62.47	44	49.99	62	32.63	80	12.07
9	68.64	27	61.93	45	49.14	63	31.55	81	10.87
10	68,44	28	61.36	46	48.28	64	30.47	82	9.67
11	68.22	29	60.79	47	47.40	65	29.37	83	8.47
12	67.98	30	60.19	48	46.50	66	28.27	84	7.26
13	67.72	31	59.57	49	45.60	67	27.16	85	6.06
14	67.44	32	58.94	50	44.67	68	26.04	86	4.85
15	67.13	33	58.29	51	43.74	69	24.91	87	3.64
16	66.81	34	57.62	52	42.79	70	23.77	88	2.43
17	66.46	35	56.93	53	41.83	71	22.63	89	1.21

The degrees of longitude vanish at the poles.

INTRODUCTION.

WHILE the tumultuous world are eagerly and almost incessantly employed in the necessary branches of agriculture, commerce and manufactures; occupied in the various arts of peace and of war; engaged in the pursuits of worldly pleasures, of wealth, or of power; a variety of sublime objects, in a great measure, escape their attention. We are surrounded by objects most magnificent, most stupendous; the visible Heavens, incomprehensible in their dimensions, evincing, by the irrefragable argument of their own existence, objects infinitely greater still; the Existence, the Eternity, the Ubiquity, the Omniscience and the Omnipotence of One JEHOVAH!

A general acquaintance with the form, dimensions, motions, and relative situations of the earth and of the celestial bodies, has a tendency, not only to divest the mind of many superstitious notions, but also to strengthen our faith in those more sublime and more important truths communicated to us by Revelation; the immortality of the human soul, the apostacy of man from God, and the benevolence and compassion of the Infinite Sovereign, as displayed in the Redemption of the world through Jesus Christ. Thus it elevates the mind infinitely above the highest possible attainments of any inferiour nature.

I hope there are none, in this enlightened age and country, who doubt the possibility of the attainment of this knowledge. Shall it be thought strange that mankind, considered as rational and immortal beings, should become acquainted with the form and dimensions of the earth, on which they exist? Shall it be deemed incredible that they should attain any knowledge of the distance of the nearest of the surrounding spheres? Is it not rather strange and unaccountable that such knowledge is not more general?

The progress which Astronomy has made is owing to the indefatigable exertions of a very small proportion of mankind. That its advancement has been so slow, is because so few have been engaged in it; the great mass of men having been occupied in a multiplicity of other concerns. But why is it that in modern times, after discoveries so great and manifold have been made, so few attain any correct knowledge of this kind? It is owing to many difficulties which lie in the way. The most formidable of these are the criminal ignorance, the inveterate prejudice and the superstitious notions of mankind. Such are the dense clouds which still hang about the horizon and prevent the rays of Science. Happy for the present age, as well as auspicious for future generations, the clouds begin to be dispersed; the difficulties seem in many instances to give way, and we are cheered by the sanguine hope that Science and Truth will finally prevail. One very conspicuous cause of reformation in this respect, which I would not fail to mention, is our enlightened Clergy; whom I would, on every occasion, devoutly exhort to use the influence they may possess, in removing superstition from the minds of men.

An exertion of the mind will be necessary in order to a thorough understanding of the subjects before us. There are some problems, the solutions of which appear exceedingly difficult on a superficial view, and have by many, in their ignorance and in their haste, been pronounced impossible; which nevertheless have been truly solved by men who have paid strict attention to the subjects.—There are many persons whose studies are very few, except in relation to their secular concerns, and who never penetrate into the depths of philosophy or the heights of astronomy. It is to be expected that such persons will be surprised at the declarations of others respecting these sublime subjects. What less than wonderful can we expect to meet with when we canvass, even to the extent of our own narrow capacities, the works of HIM whose presence fills immensity, and whose power and wisdom are infinite?

With respect to the subjects now to be considered, it would be a mere waste of time to consult the opinions of the learned among the ancients; nor need we bring into view the various absurd opinions, arising from the combined influence of ignorance, prejudice and superstition, which have so greatly prevailed among the unlearned until the present day. If truth be exhibited and maintained, the whole mass of errour must fall before the face of it.

LECTURE FIRST.

An Illustration of the Figure and Motion of the Earth, together with those of the Celestial Bodies.

IT appears to have been natural for mankind to consider the Earth as stationary, or at rest, and its general surface as a continued plane of unknown extent; and although men of science have long since discovered that these things were not so, yet these errors have been too deeply rooted in the minds of others to be easily eradicated. Surprising as it may appear, there are, even in the present generation in our own country, very many who are strangers to the true form of the Earth, and who will allow it no motion whatever. It seems necessary, therefore, that these subjects should occupy a place in the commencement of these Lectures.

Figure and motion I prefer attending to under one head, rather than separately, because of a certain connexion existing between them, and because the former, in some respects, depends upon, and can only be explained by the latter.

The sun and the planets always present circular disks towards the earth; for the planets are apparently so magnified by the telescope that their form can easily be observed. The sun and most of the planets have also, by means of spots on their disks which telescopes render visible, been observed to revolve about their axes in such a manner as to present different sides towards us at different times.

These two circumstances amount to an absolute proof that they are globular bodies. From hence we might very naturally infer that the form and motion of the earth are similar. But we are well supplied with arguments which are entirely conclusive, and therefore need not resort to analogical inferences. I propose to prove,

First, that the figure of the earth is nearly globular, or spherical, and

Secondly, that it is not a perfect sphere.

I. All men of erudition in the present age are agreed, not to give it as their opinion, but to declare it as a fact, that the figure of the earth is nearly spherical. This figure we shall prove,

1. From the phenomena of the visible heavens seen from various parts of the earth.

If the surface of the earth generally (that is excepting those small inequalities of the land, called mountains, hills, ridges and vallies, which I shall all the while except) were an extended plane; then the sun would rise and set at the same instant to all parts of this plane. Consequently the days or the nights would be of the same length in every part of the world at any time of the year. They might be longer at one season and shorter at another, but they could not be longer at one place and shorter at another. The moon, the planets and the stars, supposing the surface of the earth to be a plane, would likewise rise and set, with respect to every nation, at one and the same instant. Let a person travel east or west with a watch in good order, well regulated, and set right for the place from whence he starts. Let him also carry with him an account of the time of the rising and setting of the sun, moon, planets and stars, for every day, suited to the latitude and horizon of the place from whence he sets out. Let him travel far enough to be convinced, say one, two or three thousand miles. He will find the time of the day at the places where he arrives to differ widely from that shown by his watch; and the time of the rising and setting of the luminaries of heaven will not correspond with his account according to his watch. Will any one say that his watch has become disordered? There is a way to determine whether this be the case or not. Let him return to the place from whence he set out and observe whether it be not right. A man may be informed, by an astronomer, of an invisible eclipse of the moon, which at some other place is to be visible, for instance, at London. A correct statement may be given him of the day, hour and minute of the beginning, middle, end, and all other phenomena of the eclipse, both by his own meridian and also by that of London. He may procure two good watches, well regulated, and have them set by a person understanding astronomy, one to his own meridian, the other to that of London.—Thus equipped, he may sail to London, observe the eclipse, and be convinced. With regard to the different length of the days and nights in different latitudes, a man may convince himself without understanding mathematics. He may be at Savannah one twentieth of December and at Quebec another, and observe; or he may observe in any two places, whose difference of latitude is considerable, on any certain day, except about the equinoxes, in two different years.

Now we have what amounts to all this. These things are well known by the abundant correspondence which is carried on between all parts of the civilized and the civilizing world. A correspondent at London may inform that their longest days are 16 hours 25 minutes, and their shortest, 7 h. 35 m. another at Edinburgh may state their longest at 17 h. 20 m. and their shortest at 6 h. 40 m. a third from the mouth of the River Amazon, or from the Island of Borneo, may write that their days and nights are always just twelve hours long; and who would pretend to disbelieve? A man may as well doubt the existence of London or Edinburgh or the River Amazon, or any other thing in nature that he has never seen. Who then can believe the surface of the earth to be a flat extended plane, when in other parts of the world they see the sun or moon for hours after it is gone from our view, or before it rises to us? and when in some countries they enjoy the full refulgence of noon, while we have the cold, damp, gloomy, midnight hour?

Having thus proved, in a manner altogether unequivocal, that the surface of the earth is not an extended plane; I purpose, before I dismiss the present argument, to prove that it is convex, like the surface of a globe or sphere.

All the stars continually preserve the same situation with respect to each other; on which account they have been called *fixed stars*, in order more effectually to distinguish them from the planets.—They are three minutes and fifty-six seconds earlier every night in their rising, setting or coming to the meridian, than they were on the preceeding night. Therefore let a person observe, in the latter part of the night, what conspicuous stars are on or very near the meridian in its whole extent from the zenith to the horizon, both north and south, and take their apparent altitudes. Let him then travel due north or south; and every fifty or every hundred miles observe again the altitude of all those stars at the time when they come to the meridian; which will be earlier than at the time of his first observation, according to the number of days which have intervened, at the rate of 3 minutes and 56 seconds for each day, amounting in 60 days to 3 hours and 56 minutes. Suppose he travel north, and the surface of the earth be a plane; then the stars before him near the horizon will be but little affected by his travel; but little elevated above the horizon more than they were, seen from the place where he first observed their altitudes; because his course is so nearly directed towards them. Those higher above the horizon will be more elevated, because their direction does not so nearly coincide with that in which the person is supposed to be moving.—Those near the zenith will be most affected of all; because their direction is at right angles with the motion of the person: so that those which were but little north of the zenith will (if he go far enough) appear south of it. The stars on the meridian south of the zenith will appear to be depressed, in the same manner as those north of it will be apparently elevated; those nearest the zenith, the most affected in this respect, and those nearest the horizon the least so. This idea can certainly be distinctly communicated. If you travel north, an object which was due east soon falls to the south; one which was north-east is less affected, but is after a while (if you travel far enough) seen in the east; while an object which was due north remains due north still, and will thus continue until you arrive at it. Thus the altitude of those stars on the meridian which are nearest the horizon, will be the least affected by travelling either north or south; and that of those nearest the zenith will be the most affected. But if the earth be of a globular form, the effect will be very nearly equal with regard to every star on, or near, the meridian. I need add nothing further at present, except to inform you that the result of such experiments is well known, and to advise those who may not be convinced by the united strength of this and the succeeding arguments, to make this experiment themselves.

2. We shall prove the spherical figure of the earth, in the second place, from the universal law of Gravitation.

There is a certain principle, property, power or law of nature by which all separate bodies tend towards each other. By this principle, or law, all bodies of greater density than air, will fall to the earth, on whatever side of it they may be. By this principle, all bodies of greater density than water, will sink to the bottom of the water. The greater the density of a body is, the greater quantity of matter is contained in any certain magnitude; and consequently, as gravitation operates equally on all matter according to its real quantity, and without regard to its extent, it must operate more powerfully on a common stone than upon the same dimensions of water, and on almost any other substance than upon the same measure of air; and as water and air are fluid, they easily admit other substances which are more powerfully drawn, or attracted, to pass through them. By virtue of this principle, waters issuing from springs, ponds or lakes, will run and form channels in the lowest places which they can find. By virtue of this power or law, the surface of the ocean is in every part nearly equidistant from the earth's centre. This is the case with every particular pond or lake. By virtue of this same principle, power or law, any quantity of fluid entirely detached from all other substances, would, by the mutual attraction of its parts, assume a form very nearly spherical; and supposing it to be perfectly at rest, and beyond the sphere of attraction of any other matter whatever, its figure would be a perfect sphere. By the same law of nature, the drops of rain, in their descent, assume nearly a spherical figure.

We may then rationally conclude that the earth is of the same form; especially considering that the greatest part of its surface is covered with water; that the waters of all the oceans are connected; that these connected waters wash every shore of every continent and island; and that, by their estuaries, they so nearly bisect even the largest portions of the land.

3. We shall in the third place prove the spherical figure of the earth from its shadow in eclipses of the moon.

It may be laid down as an axiom, that a body whose shadow is always circular, from whatever side the shadow may be cast upon another body, must itself be a globe or sphere. This being the case with respect to the shadow of the earth, affords evidence of the earth's spherical figure. But in order to set this argument in the clearest light, and give it full weight, I must show that eclipses of the moon are occasioned by the shade of the earth; and in order clearly to demonstrate this, it will be necessary to prove that the moon is not a lucid body, shining by her own light, but opaque, reflecting the rays of the sun; and again, in order for this, it will be needful to show that the moon is spherical, or, at least, that she presents a convex surface towards the earth. I must then attend to these three things in the retrograde order, and show first that the form of the moon is globular, or at any rate, that the side which she presents towards the earth is hemispherical.

If the moon were revolving in such a manner as to present different parts towards us at different times, and yet her disk were at all times circular, then her sphericity were evident; but she at all times presents to us the same part. Let us for a moment take for granted the opacity or obscureness of the moon, which comes next to be proved, and we shall perceive that the manner in which the light of the sun comes on this side, and goes off from it, can be explained, or accounted for, on no other hypothesis than that of its being a hemisphere. With respect to the form of the farther side of the moon, which is forever hidden from our view, that it is also a hemisphere does not admit of actual demonstration; but if we consult analogy and the laws of nature, we may be convinced of the absurdity of any other supposition. Whoever believes it to be in the form of a cylinder, or of a cone, or of a prism or pyramid, or in any other form more irregular and unnatural, ought not to sneer at Symmes.*

I come now, in the second place, to prove that the moon is an obscure opaque body, shining only by reflecting the Solar rays. This I shall do by several observations.

First. The vicissitude of light and darkness which we observe on the moon, cannot be explained by supposing her to have a dark and a bright side, each of which is alternately turned towards us; because it is well known that the same side is always towards us. This any one may observe without a telescope.

Secondly. If the moon shone by her own independent lustre, she would always appear bright, unless some body should come between her and us, and thus obscure her partially or totally.

Thirdly. The manner in which the light comes on and goes off, is altogether unaccountable by the intervention of a body of any shape whatever; and perfectly correspondent to that in which the light of any luminary must appear to come on the side of a globe towards the observer, and go off from it, when it is moved round him towards and from the luminary.

Fourthly. The position of the sun and moon with respect to the earth, is always perfectly consistent with the position of the light and darkness on the moon.

* *John Cleves Symmes, of Ohio, who asserts the earth to be hollow and habitable within. This is perhaps the oddest, wildest, fancy of which the present age can boast.*

Finally. By the assistance of telescopes, astronomers discover many of the irregularities of the moon, with which they are well acquainted, when they are some distance within the confines of the darkness: mountains and elevations lying in the regions of the twilight: volcanoes in the interiour parts of the darkness, which do not appear to move while the darkness passes off, as they would if they belonged to an intervening body which was passing by.

Thus I have prepared the way to show, as was proposed, that eclipses of the moon are caused by the shade of the earth. Having sufficiently proved that the moon shines only by reflecting the Solar rays, it immediately follows that she will cease to shine, even at her full, if those rays be intercepted by the intervention of any other body. We know that every opaque body, on which the sun shines, prevents those rays which strike itself; and occasions what we call a shade on the side of it opposite to the sun. Thus every planet has its shade; and as the moon is never eclipsed but when she is full, that is, when in opposition to the sun, it is manifest enough that her eclipses are occasioned by the shade of the earth.

Thus the third argument which I have advanced to prove the spherical figure of the earth, may have its full weight. The earth must be globular, because her shadow is always circular, when it appears on the moon, whatever side may be turned towards it.

4. Several other considerations, on which we have not time to dwell, evince the same thing. Indeed, every circumstance any way connected

with the figure of the earth, furnishes unequivocal evidence that it is spherical. We might prove it by the dip of the horizon, which is perceptible from a small elevation, and which, if the earth's surface were a plane, could not be perceived from the summit of the highest mountains. We might prove it by the appearance of ships at a distance on the ocean, partly hidden by the convexity of the water: by circumnavigatory voyages, which have become frequent in modern times: by travels, whether by land or water, into all climates excepting very near the poles, accounts of which have been published in abundance: by the general acquaintance of mankind with almost every region of the earth's surface, with region beyond region, whether of ocean or of land, until it completes the circumference of the GLOBE.

Now for a person to dispute the rotundity of the earth against such a weight of evidence as has been presented, cannot be less than folly and madness; especially when we consider that there is not one solitary fact to support him in the wrong.

II. I now pass to the second general proposition, which was to show that although the form of the earth and of the other planets is nearly spherical, yet that it is not a perfect sphere.

Now that the figure of the earth is not a perfect sphere, excepting the small inequalities before mentioned, can only be caused by her motion. We have shown that the planets revolve on their axes, which are imaginary lines passing through their centres. Such a motion is called a diurnal revolution, because, by turning various parts of a planet to and from the sun in their turn continually, it occasions a constant succession of day and night.

We shall first show, under this head, that the earth has such a motion.

Secondly, that such a motion would prevent her figure from being a perfect sphere.

1. In the first place, that the earth revolves on her axis we might infer from analogy, it having been determined by observation that the other planets have such a motion. But not to put too much stress on analogy, though it seems in the present case to have considerable weight, I shall pass on.

Secondly. It being certain that either the globe revolves daily on her axis, or that the sun, moon and stars perform a revolution daily around the earth, I shall prove the former by disproving the latter.

And here, if it were possible for an Almighty arm to grow weary, I might draw an inference in my favour, from the ease with which the earth might be turned on her axis, in comparison with the labour which it would require to carry such a vast number of such huge globes through an extent of space so inconceivable. But as nothing is hard with the Almighty which is in the nature of things possible, I shall argue only in the manner following.

First, from the known laws of nature,

Secondly, from the evident absurdities of a contrary supposition, and

Thirdly, from the total want of evidence on the opposite side of the question.

First. I shall argue from the known laws of nature.

First, Gravitation. This we have previously mentioned. This is a known law: known by its constant operation. It is the operation of this law which causes what we call the weight of bodies. This is often called the *centripetal force*.

Secondly. There is another law, called the *centrifugal force*, from its effect among the planets. This is that law by which a body, after having received an impulse, continues to move, forever if it meet with no impediment, in a straight line, in the direction and with the velocity communicated by the impulse: so that if, after the lapse of ever so many billions of ages, it should strike any object, the momentum with which it would strike would be the same with the impulse first given to it. This is that law without which you might throw a stone with all your strength, and it would proceed no farther than the length of your arm: without which a ball, issuing from the barrel of a musket or the mouth of a cannon, would stop as soon as the force of the powder ceased to impel it: without which falling bodies would move nearly with an uniform velocity, and strike with no greater momentum than their gravity. This law, as I said, carries bodies in a straight line, with undiminishing velocity, and forever, if they meet with no interruption or resistance. A body thrown into the air does not pursue a direct line, because the attraction of the earth operates upon it; it does not move with an uniform velocity, because the air impedes its progress; it does not continue in motion forever, because either of these impediments alone is sufficient to stop it.

From the combined influence of these laws we infer two things.

First. We infer that one body may move round another; as when a small body should be impelled in a direction at right angles with a larger one, the attraction of the larger body will turn the smaller one from the direct line, which it would otherwise pursue, and cause it to revolve in a circle or an ellipsis round itself. The attraction of the larger body, acting in a perpendicular direction to the motion of the smaller one, could have no tendency either to retard or to accelerate it. If by any law of nature, a body, after being put in motion in a circle, would continue thus to move voluntarily, or of itself; then the attraction of the larger body might operate in drawing the smaller one nearer to itself. But this is not the case. If a gun barrel were uniformly curved, yet a ball discharged from it would not pursue a curve line. A body, therefore, in motion round another has a tendency continually to pursue a direct line: and this tendency perpetually balances the attraction of the body around which it revolves: so that, by the combined influence of these two laws, it would forever revolve, unless some interruption should take place. This tendency to pursue a direct line, which would carry every revolving body away from the body around which it revolves, has therefore been called the centrifugal force.

If you fasten a weight to one end of a line, and, taking hold of the other end, set it to revolving (in a horizontal direction perhaps will be best) you will immediately perceive its tendency to fly off, or its centrifugal tendency.

In the second place we infer that a heavier body will not move round a lighter one; because the attraction of the lighter body cannot balance the centrifugal force of the heavier one: but that the heavier body (if the disproportion be great) will, by virtue of its centrifugal tendency, nearly pursue its own direction, and, by its attraction, draw away the lighter body with it; because an inferiour power cannot overcome a superiour.

From the foregoing laws and the inferences we have drawn from them, it appears evident that the sun cannot move round the earth unless it be lighter than the earth. Now the real magnitude and distance of the sun can receive no attention in the present lecture; but it is needful, in order to complete my present argument, to show that it is much larger than the earth; which I will endeavour to do by a very plain and certain method. As I do not design to enter into the subject of density, I will for the present suppose that the sun may be so much less dense than the earth, that if it be equal in size, still it may be enough lighter to revolve around it. What remains on this head is to show that it is much larger than the earth.

On the supposition that the earth and the sun are equal in size, the apparent magnitude of the earth seen from the sun is equal to that of the sun seen from the earth; or, in other words, the sun's horizontal parallax is just equal to his apparent semidiameter: so that if the centre of the sun were in the rational horizon, which is a great local circle in the heavens, whose plane passes through the centre of the earth, dividing the heavens and the earth into upper and lower hemispheres, the upper edge of his disk would be in the sensible horizon, which is parallel to the former, and whose plane touches the surface of the earth at the place of the spectator. Therefore, to an observer at the equator, the sun's centre will be less than half the time above the plane of the sensible horizon, and more than half the time below it; although it must be just half the time above, and half below, the plane of the rational horizon.. This difference is the effect of a parallax, which is occasioned by our distance from the earth's centre. The horizontal parallax is an angle of depression, causing a luminary to rise later and set earlier than otherwise it would do. The parallactic angle decreases as the distance increases; for the distance between the rational and the sensible horizons is just the semidiameter of the earth, which seen from a greater distance must evidently appear under a less angle. But the sun's horizontal parallax is just equal to his apparent semidiameter, on this supposition; because his semidiameter is here supposed to be just equal to that of the earth. The sun's apparent semidiameter is found by observation to be, at a mean rate, sixteen minutes of a degree; which turned into time, at the rate of 360 degrees to 24 hours, amounts to one minute and four seconds by computation. This one minute and four seconds of time is the effect which the sun's horizontal parallax would have on his rising and setting at the equator, where otherwise he would always rise and set at six o'clock, and the days and nights would be always equal. The day would be 4 minutes 16 seconds shorter than the night. In our latitude, nearly 41 degrees north, the effect of such a parallax on the sun's rising and setting, and on the length of the day and night, would be increased by one third, on account of the obliquity of the horizon to the equator; and could be perceived with as much advantage, because the very second of time when the sun would otherwise rise and set might be determined by calculation. But I hasten to state the argument which I would here raise, and to dismiss this part of the subject.

The effect of such a parallax could easily be perceived by a well regulated clock; nay, the fourth part of it could certainly, and would unquestionably have been perceived by the nice observations which have been made; whereas the true parallax is so small that its effect in this way is entirely imperceptible. At any rate then the sun's distance must be four times as great as such a supposition would make it, for the fourth part of such a parallax could and would have been perceived: and consequently he must be, at least, four times as large in diameter as the earth: and as the content of solid bodies, of a similar figure, is in proportion to the cubes of any of their corresponding dimensions, it results that the sun is *at least* 64 times as large as the earth, and therefore that it cannot revolve around it.

Thus I have proved the revolution of the earth on her axis, by proving from the laws of nature that the sun does not move daily around the earth.

Second. I was in the next place to argue, in support of the earth's diurnal motion, from the evident absurdities of the contrary supposition.

If we deny the diurnal revolution of the earth, then we suppose, as was before observed, that the sun, moon, planets and stars move round the earth once every day; the absurdity of which hypothesis will appear from three considerations.

First, from the various times in which the heavens appear to revolve, seen from the different planets of this system. To an observer on the sun, the heavens would appear to revolve once in 25 days, 14 hours and 8 minutes; this being the time of the sun's revolution on his axis by observation. Seen from Venus, the heavens appear to revolve in 23 hours, 21 minutes and 7 seconds. Observed from Mars, the time of an apparent revolution of the heavens is 24 hours, 39 minutes and 21 seconds. Seen from Jupiter, it is 9 hours, 55 minutes and 50 seconds, and from Saturn, 10 hours, 16 minutes & 19 seconds. It being impossible for the sun, or the sideral heavens, to revolve around one planet in one period of time, and around other planets in other different periods; we therefore conclude that it is only an apparent revolution of the heavens, occasioned by the rotations of the planets on their axes.

In the second place, it appears absurd that one body should move round an imaginary line, conceived to be drawn from another, and leave the other body itself at a vast distance from the plane of its path or orbit; which is the case with most of the stars, if we admit the apparent revolution of the heavens to be real.

Thirdly, on this supposition there are some very inconsistent motions among the planets. The sun revolves sometimes at a greater and sometimes at a less distance from the earth, as is evident from the difference observable in his apparent magnitude. The planets vary vastly more in their distances, at least some of them, as is evident from the same circumstance. Some are nearer than the sun at one time and more distant at another. Some are nearest only when near their conjunction with the sun, others only about the time of their opposition to him. All these circumstances, and others, which time forbids me to mention, are perfectly unaccountable on this supposition; while if we admit the diurnal motion of the earth, they are perfectly consistent with the laws of nature.

Third. All the arguments which have been urged in support of the earth's diurnal motion, must have their full weight, when we observe, in the third and last place, that there is a total want of evidence to the contrary.

We have certainly found no evidence to the contrary in *Nature;* and it is equally certain that none can be found in *Scripture.* There can be no weight in those common and vulgar objections, that people cannot stand on their heads; that the waters would be spilled out of the wells, mill-ponds, &c. &c. They are too frivolous to be seriously attended to. We have not spoken of people standing on their heads, but of the *Universal Law of Gravitation,* that principle which maintains the Order of nature; without which the waters of the great Deep might rush from their beds and drown us upon the heights of the Alps or the Appenines, the Alleghany or the Andes; and without which we could as easily stand on our heads as on our feet.

There are some who bring an objection from Scripture. "Joshua,' say they, 'commanded the sun and moon to stand still; and how could this have been proper if the sun did not run?" I answer, That was the only proper manner in which he could speak on the occasion. With respect to the earth, the sun, moon and stars appear to run; and who is there, even in modern times, that does not, in all his ordinary discourse, speak as if the earth were standing still, and the luminaries of heaven revolving daily around us? A person who so strenuously adheres to the literal signification of every expression he may find used in Scripture, must renounce either the Scriptures or his reason. Will he suppose that he must hate his father and mother, and his own life, in order to be a worthy disciple of the Lord Jesus, because, according to the literal sense of the words, Christ has said what amounts to this? Must he not renounce his reason in order to believe such gross absurdities and such palpable contradictions as are to be found in the Bible; or else reject the Bible altogether as being repugnant to reason? How much better to "show the reason of a man," and understand only what was intended to be understood! The Israelites wanted longer time, on a certain day, to pursue their enemies and complete their victory. The Lord was pleased to grant this thing. Joshua, influenced by the Holy Spirit, bade the sun and moon stand still; and they stood still! He made use of common language, in the foundation of which the earth is always considered as at rest, and therefore his expressions can be no evidence whatever respecting any point in astronomy.

Thus I have proved the diurnal motion of the earth (which was the first thing proposed under the second general head) from the known laws of nature; from the absurdities into which a contrary supposition would involve us; and from the total want of evidence to the contrary.

2. The next proposition was to show that such a motion would prevent the figure of the earth from being a perfect sphere.

I observed, in the former part of this lecture, that, by virtue of the principle of gravitation, any quantity of fluid, entirely detached from all other substances, perfectly at rest and beyond the sphere of attraction of any other matter whatever, would assume the figure of a perfect sphere. Let us now suppose this body of fluid, after assuming such a figure, should be set to revolving on a straight line passing through its centre. Such a motion would occasion a centrifugal force. Every particle of the fluid, at any distance from the line or axis on which the body would revolve, would have a tendency to recede farther from it; and the farther the situation of any particle might be from this line, the greater would be its tendency to recede from it. In consequence of this, its diameter in the direction of its axis would suffer a diminution, while in any direction perpendicular to it, it would be increased.—Thus, by reason of this motion; it would deviate from a sphere, and assume the form of an oblate spheroid. This then is the true figure of the earth.

I might further observe that, by the actual measurement of a degree of the meridian in different latitudes, the spheroidal figure of the earth has been reduced to a mathematical demonstration: and not only so, but it has been ascertained that the polar diameter falls short of the equatorial diameter 34 miles.

I do not suppose that the earth has assumed this figure; but that the Creator gave it such a figure as should correspond to the motion which he had communicated, or intended to communicate to it. For if it had been originally formed a perfect sphere, and there had been land situated about the equator and the poles, as well as elsewhere, with about the same elevation above the surface of the water with which we now find it, and no change had since taken place except such as would be produced by its motion; we should now expect to find no land in the equatorial regions, and mountains about the poles elevated seventeen miles above the level of the ocean.

The figures of those celestial bodies also, which have a similar rotation on their axes, are more or less oblate, in proportion to their magnitudes and the velocity of their rotations.

LECTURE SECOND.

The causes of the various Phenomena of the Visible Heavens explained.

HAVING, in the preceding Lecture, proved, among other matters, the diurnal motion of the earth and of the other planets; we have now a solid foundation on which to proceed to the explanation of the various appearances which we observe in the surrounding heavens.

All the luminaries which nightly besprinkle the firmament, with the exception of a few, are called stars; and having, throughout all generations, remained very nearly in the same situation with respect to each other, have, from this circumstance, obtained the appellation of fixed stars. A desultory observation of the heavens is sufficient to discover that there is a motion among a few of the luminaries, by which they continually vary their positions. These have on this account been called wandering stars, or planets. The phenomena which we behold are at once a decisive proof that the planets have another and a different motion from that which was proved in the former lecture; a motion by which they change their places with regard to space; and this motion when explained, will account for the phenomena.

I shall in the first place shew that the planets revolve around the sun. Secondly, shew the manner of this motion, and the phenomena resulting from it. Thirdly, I shall attend to the motions and phenomena of the moon.

I. The first proposition was to shew that the planets move around the sun; which motion we shall call their annual revolution.

All the planets are found by observation to perform revolutions around the sun. They are seen on every side of the sun in the direction of their motions. The paths in which the planets move round the sun are called their orbits; and every planet is observed to pass between the sun and all the stars in or near the plane of its orbit, or path. We find that the fixed stars rise and set three minutes and fifty-six seconds earlier every night than they rose and set on the preceding night, amounting in a year to one apparent daily revolution more than the sun apparently performs; and it is evident that such must be the effect of an annual revolution of the earth from west to east. If the earth's revolution on her axis were stopped, and in this situation, she were carried once round the sun from west to east; the sun would then appear to us to perform a revolution round the earth the same way, which would not be the case with the stars, because they are not included in the earth's orbit, but are far beyond the confines of the system of the sun and planets. Now the effect of the earth's annual revolution cannot be destroyed by her diurnal revolution; it must therefore occasion a diminution of one from the number of apparent daily revolutions of the sun from east to west, which would otherwise be produced every year by her revolution on her axis.

It might be urged that although neither the sun nor the stars go daily around the earth, yet that an annual motion, either of the sun eastwardly or of the stars westwardly, would account for this acceleration of the stars in their apparent daily revolution.

Such a supposition is inadmissible; inasmuch as we have proved in the preceding lecture that the sun cannot go round the earth at all according to the laws of nature, it being much larger than the earth; and inasmuch as the earth, with regard to most of the stars is at a vast distance from the plan of their supposed orbits. But even if the supposition could be admitted, that the stars perform an annual revolution round the axis of the earth conceived to be produced or extended north and south through the planes of their apparent annual orbits; we should have as much reason to suppose that these same stars perform a revolution round Jupiter in a period almost twelve times as long, and on an axis some what different in its direction; at least the inhabitants of that planet would have as good reason to suppose so. No two planets would be found to agree as to the time of the performance of such a revolution; therefore it must pass for an absurdity. Besides, the earth, and every planet, must go round the sun, in order to acquire a centrifugal force sufficient to balance the sun's attraction.

II. The next thing proposed is to show the manner of their motions, and the phenomena resulting from it.

Here I would make a few general observations, and afterwards be more particular.

1. The planets do not move in circles, but in orbits more or less elliptical, having the sun in one focus of their respective orbits; so that every planet is nearer the sun in one point of its orbit than in

any other, which point is called its perihelium, and in the opposite point the planet is at its greatest distance from the sun, called its aphelion.

2. The planets do not all move with the same velocity in their respective orbits. Those farther from the sun move slower, and those at a less distance have swifter motions.

3. The motion of any particular planet is not uniform. Every planet's motion is swiftest in its perihelium and slowest in its aphelion.

4. The orbits of all the planets lie in different planes. The orbit of the earth is called the ecliptic. The planes of the orbits of all the other planets intersect the plane of the ecliptic, making small angles with it, and therefore one half of the orbit of every planet lies on the north side of the ecliptic, and the other half on the south side. The points where the orbits of the planets intersect the ecliptic are called their nodes; that in which a planet crosses the ecliptic from south to north is called its ascending node, and where it crosses from north to south is the decending node. The nodes of the different planets lie in various parts of the ecliptic.

5. The axes of the different planets are variously inclined to the planes of their respective orbits, and to that of the ecliptic.

These several things have all been determined, together with the particulars relating to them, by the nice observations of astronomers; and as they all serve to explain certain phenomena, so by the phenomena their own truth is confirmed.

6. From the principles of gravitation and centrifugal force, we infer that the velocity of a planet in its orbit must be proportioned to its distanse from

the sun, in such a manner that the two forces may be equal; and therefore the longer a planet takes to perform its revolution round the sun the greater is its distance from the sun, and the contrary.—Thus we discover the order of the planets in the system to be as follows; the first or nearest the sun is Mercury, 2 Venus, 3 the earth, 4 Mars, 5 Vesta, 6 Juno, 7 Ceres, 8 Pallas, 9 Jupiter, 10 Saturn, 11 Herschel. Mercury and Venus, lying nearer the sun than the earth does, are called inferiour planets. They change their appearance, waxing and waning like the moon; being opaque bodies, and shining only by reflecting the Solar rays, as is the case with all the planets. All the other planets are farther from the sun than the earth, and are therefore called superiour planets. These do not change their appearance like the inferiour planets, because their enlightened side is turned so nearly towards us at all times.

7. The inferiour planets, being situated nearer the sun than the earth is, and moving sooner round him, may sometimes be in conjunction with the sun seen from the earth, when they are beyond the sun in the most distant part of their orbits; which is called their superiour conjunction: and at other times they may be in conjunction on this side of the sun in the nearest part of their orbits; which is called their inferiour conjunction: but they can never come in opposition to the sun. The superiour planets are sometimes in conjunction with respect to the sun and sometimes in opposition, but when in conjunction they are far beyond it.

8. The real motions of all the planets are from west to east around the sun. The apparent mo-

tion of an inferiour planet is always retrograde, or from east to west, about the time of its inferiour conjunction; that of a superiour planet, about the time of its opposition.

Having made these few general observations respecting the planets, I shall now be a little more particular.

1. The Sun is a vast globe near the centre of the Solar System, around which all the planets and comets revolve, and from which they derive their light and heat. The sun has a very slow motion round the centre of gravity of the whole system, which is near his own centre. His motion is very irregular, on account of the number of the planets by whose attraction he is thus affected. Were it not for this motion the sun would be too easily drawn away from his station by a balance of attraction of the planets, which is sometimes considerable. The sun's motion, however, is not subject to the same law or rule to which the motions of the planets are subject, but on the contrary he must move slowly around the centre of gravity because he is near it, or otherwise he would by his centrifugal force be carried away and the system would be deranged. By observing the spots on his surface, astronomers have found that the sun revolves on his axis once in 25 days, 14 hours and 8 minutes.

2. The nearest planet to the sun is Mercury, which performs a revolution round the sun from any star to the same again, or what is called a sideral revolution, in 87 days, 23 hours, 15 minutes and 44 seconds. The orbit of Mercury is more elliptical or eccentric than that of any other of the

seven first discovered planets, and is inclined to the ecliptic in an angle of seven degrees; which is also a greater inclination than the orbit of any other of the seven has. Mercury is so small and so near the sun (being never more than about 28 degrees distant from him) that he is seldom observed. He moves, at a mean rate, either from his inferiour or his superiour conjunction to the same again in 115 days, 21 hours, 3 minutes and 34 seconds; which is almost 28 days longer than he takes to make a revolution round the sun, owing to the distance which the earth advances in the mean time. If the orbit of Mercury lay in the plane of the ecliptic, he would, at every inferiour conjunction, pass between the centre of the sun and the earth's centre; and might be seen like a dark spot passing over the sun's disk. Such a phenomenon is called a transit. The same observation will also apply to Venus, which is likewise an inferiour planet.—A transit will take place when either Mercury or Venus comes to its inferiour conjunction at, or very near, either of its nodes; but at all other times the planct's distance from the plane of the ecliptic will be so great, either north or south, that it will pass the conjunction without coming between the earth and any part of the sun's disk. Mercury's last transit happened November 11th, 1815, invisible here; the next will take place November 4th, 1822, at half past 9 o'clock in the evening, also invisible. The time of his revolution on his axis has not yet been determined.

3. Venus is the next planet in the order of the system. Revolving within the earth's orbit, she is therefore called an inferiour planet. Her sideral

revolution is performed in 224 days, 16 hours and 49 minutes; and she goes from one inferiour conjunction to another, at a mean rate, in 583 days, 22 hours, 5 minutes and 28 seconds. Her orbit is less eccentric than any other of the planetary orbits, and is inclined to the ecliptic in an angle of 3 degrees, 23 minutes and 33 seconds. There was a transit of Venus across the sun's disk in the year 1761, and another in 1769. The next will take place in the year 1874, beginning in the evening of the 8th of December and ending on the morning of the 9th, therefore invisible in America. The greatest elongation (or angular distance) of Venus from the sun, is about 48 degrees. When she is east of the sun, she sets in the evening and is called evening star; and when she is west of the sun, she rises before him in the morning and is called morning star.

4. The earth (which we inhabit) is the third planet in the order of the system. The earth's orbit is the ecliptic, in the plane of which the earth and the sun always are. If the axis of the earth were perpendicular to her orbit, the sun would be always on the equator, and would always rise and set at six o'clock to every part of the world, and there would be no vicissitude of seasons, such as spring, summer, autumn and winter. But her axis is at present (1820) inclined to the plane of her orbit in an angle of 23 degrees, 27 minutes and 46 seconds, subject to a diminution of 52 seconds in a century. From this inclination it evidently results that one end of her axis, or one of her poles, must be turned more towards the sun in one part of her orbit, and the other end, or pole, turned more to-

wards him in the other part of her orbit. This sufficiently explains the phenomenon of the sun's declination north and south from the equator, the maximum, or greatest extent, of which is always equal to the inclination of the earth's axis to the ecliptic. This also accounts for the change of seasons; for although we are not obliged to believe the sun to be a body of fire, yet it is very certain that heat is produced by his rays, and that the degree of heat produced will, generally speaking, be greater or less, in proportion to the less or greater obliquity with which the rays of light strike the surface of the earth; because when the obliquity is greater, fewer rays will strike on every square mile, or everv acre or foot of land.

Another circumstance, claiming attention in this place, is the variation in the length of the days and nights in northern and southern latitudes, whereas at the equator there is no variation.

It is not difficult to conceive that the horizon of that place on the equator and on the same meridian with us, intersects our horizon in the east and west points; and that the northern half of it is elevated above ours and passes through the north pole, and the southern part depressed below ours, passing through the south pole. Now it is plain that if the sun decline from the equator towards the north, he must cross the equatorial horizon after he rises above ours, and again before he sets to us; consequently our day must be longer than twelve hours. The hour of the day is the same here as at any other place on the same meridian, but the sun rises earlier and sets later than at the equator, when his declination is north. It will be perceived that the south declination of the sun would have the contrary effect; and that the whole would be inverted with respect to a place in the southern hemisphere; and that the circumstances are the same with regard to any other meridian whatever; and that the effect of the latitude of the place and of the declination of the sun, in this respect, will be more or less, in proportion to the greater or less latitude and declination. It is principally owing to the great length of the days (the heat having longer time to accumulate) that it is found to be nearly as warm at a considerable distance from the equator, in summer, as it is at the equator.

One more circumstance demands explanation here. At the poles of the earth it is six months day and six months night.

With respect to either pole, the equator is in the horizon. When, therefore, the sun crosses the equator he rises to one pole and sets from the other. When he is visible, at either pole, he apparently revolves continually in a lesser circle parallel to the horizon, rising gradually higher and higher above it, until he reaches the maximum of declination, and then sinking lower and lower until, arriving at the equator, he sinks below the horizon. The sun shines nearly eight days longer at the north pole than at the south pole, on account of the earth's unequal motion in her orbit, and the situation of her aphelion.

The equation of time arises partly from the same cause, and partly from the inclination of the ecliptic to the equator. We shall now proceed to the superiour planets.

5. The fourth planet in order from the sun is Mars. He finishes his revolution round the sun in

686 days, 23 hours, 30 minutes and 39 seconds; so that his year is almost as long as two of ours. The earth goes round the sun in less time than any of the superiour planets, and therefore brings them sometimes in conjunction with the sun, and at other times in opposition to him. After leaving Mars at one of his oppositions, the earth overtakes him again at another, in 779 days, 22 hours, 28 minutes and 17 seconds, at a mean rate. The orbit of Mars is more eccentric than that of any other of the original planets, except that of Mercury. Its inclination to the ecliptic is 1 degree and 51 minutes.

There is one phenomenon of Mars worthy of attention. Although he appears very small in general; yet there are times when he shines with extraordinary brilliancy. In order to explain this circumstance, I would observe that it can only occur about the time of his opposition to the sun; at which time he is nearer the earth than at his conjunction, by the whole diameter of the earth's orbit, and nearer, by the semidiameter of it, than his mean distance. This must occasion a vast difference in the appearance of Mars, considering that he is the next planet above the earth in the system, and that therefore the diameter of his orbit does not, by a very great proportion, exceed that of the earth. Venus, the next planet inferiour to the earth, would shine much brighter at her inferiour conjunction than at any other time, on account of her proximity, were it not that she is lost in the Solar rays, and that her dark side is also turned towards us. The earth shines vastly brighter to Venus at such a time than at any other. But there is a great difference between one opposition of Mars and another, in regard to his lustre. One is much more extraordinary than another in this respect. What can account for this?—Nothing but the great eccentricity of his orbit. That the orbit of Mars is very eccentric, is evident from his unequal motion; on account of which he is frequently brought to his conjunction or opposition sooner or later than the mean time by more than twenty days. When therefore Mars is in his perihelium, at the time of his opposition, it will be the most extraordinary, and when he is in his aphelion at such a time, it will be the least so. The opposition of Mars in the summer of 1813 was very remarkable. The three next, in the autumn of 1815, in December of 1817 and January of 1820, continued to be less and less so; and that which is to take place in February, 1822, will be the least observable of all. Those which will happen in 1830 and 1845 will both be worthy of notice.

6. The fifth, sixth, seventh and eighth planets in the system, are Vesta, Juno, Ceres and Pallas. These are very small planets, and have all been discovered since the commencement of the present century. They have obtained the general appellation of *asteroïds*. Dr. Olbers discovered Vesta on the 29th of March, 1807. Its revolution round the sun is performed in about 1155 days, or three years and two months. Mr. Harding discovered Juno, September 1st, 1804. Her revolution is performed in about 1589 days, or four years and four months. Ceres was discovered by M. Piazzi, January 1st, 1801. The revolution of this planet is completed in 1681 days, 12 hours and 9 minutes. On the 28th of March, 1802, Dr. Olbers discover-

ed Pallas, which completes a revolution in 1703 days, 16 hours and 48 minutes.

The comparative distances of the old planets from the sun had long been known, and their regularity, except between the orbits of Mars and Jupiter (where there seemed too wide a space unoccupied) induced some astronomers to believe that another planet might be discovered in this region. The discovery of Ceres greatly strengthened this conjecture; but the opinion which it seemed to establish, respecting the uniformity of the system, was completely overturned by the discovery of Pallas and Juno. Dr. Olbers, however, imagined that these small celestial bodies were only fragments of a larger planet, once existing in those regions, which had been burst assunder by some internal convulsion; and that other fragments might yet be discovered. He also conceived the idea that, although their orbits are differently inclined to the ecliptic, yet, as they all must have diverged from the same point at first, so they must have two common points of reunion, or two nodes in opposite points of the heavens, through which all of them must sooner or later pass. One of these points was found to be in Virgo and the other in Pisces; and it was actually in the latter of these points that Mr. Harding discovered Juno. With a view, therefore, to discover other fragments, Dr. Olbers observed, thrice a year, all the little stars about those points, until his labour was crowned with success in the discovery of Vesta. Such circumstances, I think, render the probability of such an explosion very great.

Before I proceed I beg leave to state that, according to an opinion which has begun to prevail among philosophers, those meteoric stones, which have fallen to the earth in so many instances, and concerning the origin of which there have been so many and so inconsistent opinions among mankind, are some of the smaller fragments of the once existing planet. It is not found difficult to believe that an explosive force sufficient to throw off the larger masses to such a distance as not to be drawn together again by their mutual attraction, might send out thousands of smaller fragments with such violence that they would proceed (so to speak) beyond the sphere of the attraction of the larger masses, and be found in almost every part of the system. Many of these small fragments might fall immediately to the sun, or light on some of the planets; but much the greater number would very probably continue, for many ages, to revolve about the sun or some planet. This depends upon the direction of their respective impulses in relation to the system. Those revolving round the sun, from the interference of their paths with the planetary orbits, might sometimes come in contact with planets. Those circulating round planets might, from the resistance with which they meet, even in passing through the higher regions of the atmospheres, be so retarded in their motions as to fall. What other theory can account for bodies of such weight being at such a height from the earth as these are seen to descend from? What other theory can account for the velocity with which they move sometimes in a direction nearly horizontal?

Time forbids me to dwell longer on this subject. Persons who wish to pursue it are referred to the

New Edinburgh Encyclopedia, where they will find it treated at large.

7. The ninth planet is Jupiter. He is five times as far from the sun as the earth, as is evident from the time of his annual period, which is 4332 days, 11 hours and 51 minutes, or nearly 12 years. As the quantity of light which the planets receive from the sun, is in inverse proportion to the squares of their distances from him, it follows that Jupiter receives only one twenty-fifth part as much as the earth. The earth overtakes Jupiter and brings him in opposition to the sun, at a mean rate, once in 398 days, 21 hours, 14 minutes and 15 seconds. The inclination of his orbit to the ecliptic is an angle of 1 degree, 18 minutes and 51 seconds, diminishing at the rate of 22 seconds in a century.

Jupiter is attended by four satellites, or moons, which revolve around him at different distances and in different times, and are carried along with him around the sun. These secondary planets, or satellites, are easily seen by the help of a telescope, and I have heard a person assert that they might be seen about the time of Jupiter's opposition without such assistance.

8. Ascending still higher in the system, we arrive at Saturn, the tenth planet. His distance from the sun is nearly twice as great as that of Jupiter, his revolution being performed in about 29 and a half years. Saturn comes to his opposition once in 378 days, 2 hours, 11 minutes and 24 seconds.—The inclination of his orbit to the ecliptic is 2 degrees, 29 minutes and 38 seconds. Saturn has 7 satellites, or moons, and is also surrounded by a vast ring, the plane of which forms an angle with

the plane of the ecliptic of about 30 degrees. The orbits of the six first satellites appear to be in the plane of the ring, but the seventh evidently varies from it. The ring is a singular curiosity, and may be seen by an ordinary telescope.

9. The eleventh planet, and the one most remote from the sun of any yet known, is Herschel; so called in honour of Mr. William Herschel, by whom it was discovered on the 13th of March, 1781. It is twice as far from the sun as Saturn, and nineteen times the distance of the earth. The light, therefore, which they receive from the sun is only one 360th part of the quantity which we receive; yet, according to modern philosophers, it is about 250 times as much as our full moon affords us, which, I suppose, is sufficient for every purpose of life. The degree of their heat probably depends, in a great measure, upon the density of their atmosphere; and who knows but this may, in some degree, also affect their light? Herschel performs his revolution in 83 years, 150 days and 18 hours, and is in opposition to the sun once in 369 days, 16 hours, 33 minutes and 36 seconds. The inclination of his orbit to the ecliptic is 46 minutes and 20 seconds. This planet is accompanied by six secondary planets, or moons. All these move in a direction nearly perpendicular to the orbit of the primary, and contrary to the order of the signs.

Thus, to use, with a little alteration, the words of a justly celebrated female writer, we have arrived

> "At the dim verge, the suburbs of the system,
> Where cheerless' Herschel, 'midst his wat'ry moons,
> . . . . . . majestic sits
> In gloomy grandeur, like an exil'd queen
> Amongst her weeping handmaids."

III. From this lofty pinnacle we must now descend, as was proposed, to take a view of that satellite which accompanies the earth, and which we call the *moon*. Here I shall observe some order in attending to the principal circumstances which affect the moon's motion and produce the phenomena which we behold.

1. The moon moves from west to east around the earth, as the earth does around the sun, though not in the same plane. She *appears* to move from east to west, because the revolution of the earth on her axis is performed in so much less time than that of the moon in her orbit. The effect of the moon's real motion is seen in her rising, southing and setting, later and later, day after day or night after night. The moon completes her revolution round the earth in 27 days, 7 hours, 43 minutes and 5 seconds; which is called her periodical revolution. During this period the earth advances so far in her orbit (by which the sun appears to be advanced) that it will take the moon more than two days longer to overtake the sun again. The moon goes from one change, or conjunction with the sun, to another, at a mean rate, in 29 days, 12 hours, 44 minutes and 3 seconds. This period is called a mean Lunation.

2. The moon's orbit is considerably eccentric. That point in which she is nearest the earth is called her perigee, and in this place she moves with the greatest velocity; and the opposite point, where she is farthest from the earth, and her motion slowest, is called her apogee.

3. The moon's apogee and perigee move forward in the zodiac, making a complete revolution

in 8 years, 309 days, 8 hours and 20 minutes. Thus the moon not only moves with greater and less velocity in different parts of her orbit, but with the greatest velocity, at one time, where at another time her velocity is least, and the contrary.

4. If the moon's orbit were situated in the plane of the ecliptic, it is evident that she would decline from the equator north and south once every revolution (that is about 27 days) as much as the sun does once every year. This then accounts, in general, for the moon's running high and low. But there is another circumstance to notice respecting the declination of the moon. Some years she declines much farther from the equator than she does others. This leads me to observe

5. That the moon's orbit is inclined to the ecliptic in an angle of about 5 degrees and 9 minutes. Now if the moon's ascending node, where her orbit crosses the ecliptic from south to north (with the forementioned inclination) were situated at the beginning of the sign Aries, where the ecliptic ascends north from the equator in an angle of 23 degrees, 28 minutes nearly; then the obliquity, or angle of inclination, of the moon's orbit to the equator would be equal to the sum of both those angles, viz. 28 degrees and 37 minutes. This then would be the maximum of the moon's declination, on the supposition that her nodes were thus situated. But if the descending node were in the beginning of Aries, and the ascending node in the opposite point, or beginning of Libra; then the inclination of the moon's orbit to the equator, or maximum of her declination north and south from it, would be equal only to the difference of those angles, viz. 18 de-

grees and 19 minutes. But the question arises, Where are the nodes situated? In answer to this, I would observe

6. That the nodes of the moon's orbit have a slow retrograde motion, and complete a revolution round the ecliptic in 18 years, 224 days and 5 hours. This fully explains the mysterious phenomenon of the moon's running so much higher and lower at one time than at another. When the nodes are situated according to the former supposition (which is the case the present year, 1820) the moon will run remarkably high in one part of her orbit, and low in the opposite part of it. She will decline 28 degrees and 37 minutes north and south from the equator, making a variation in declination of 57 degrees and 14 minutes; and this variation will take place in about fourteen days; which is half the time of her revolution, for in moving from the highest point of her orbit to the lowest point, she goes through but one half her orbit. Her declination will vary the most rapidly when she crosses the equator; and if she should at the same time be about her perigee, the daily variation will be increased. This accounts for the vast difference in her declination which some have been surprised to find take place in a day or two.

7. If the plane of the moon's orbit were in coincidence with the plane of the ecliptic, she would eclipse the sun at every change, and be herself eclipsed at every full; but as her orbit is so much inclined to the ecliptic, it is manifest that no eclipse can take place except when she is at, or near, one of her nodes, at the time of her full or change; because, in any other part of her orbit,

she will be either too far north or too far south, from the ecliptic, either to cast her penumbra on the earth at her change, or to fall herself into the earth's shadow at her full. The limits of Solar eclipses are generally stated at seventeen degrees from either node on each side; those of Lunar eclipses at twelve degrees. But the limits of eclipses, like every thing else belonging to the moon, are subject to some variation. An eclipse of the sun is seldom total at any certain place, and cannot continue so but a few minutes; because the moon's diameter seen from the earth, when she is in perigee, so little exceeds the sun's, even when the earth is in aphelion. The limits of Lunar eclipses are smaller and their number fewer than those of the sun, because that part of the earth's shadow, through which the moon passes in the time af a Lunar eclipse, is less than the earth; but there are many more total eclipses of the moon than of the sun, because that part of the earth's shadow is much larger than the moon. On the same account the moon is totally eclipsed for an hour and three quarters, as in February, 1812.

8. The moon's orbit is rendered more eccentric than its mean state when the sun is in the same direction with either her apogee or perigee, and less so when the sun is either three or nine signs from her apogee.

9. The moon's orbit is dilated when the earth is in her perihelium, or nearest to the sun, which is in winter, and contracted in summer, when the earth is in her aphelion.

Thus the eccentricity of the moon's orbit, the inclination of the ecliptic to the equator and of the moon's orbit to the ecliptic, the motion of the apogee and perigee, the retrograde motion of the nodes, the variation of the eccentricity, and the dilation and contraction of the orbit, together with several other smaller causes which might be mentioned, combine to render the moon's motion extremely various, in regard to her longitude, latitude, declination, fulling and changing, southing, rising and setting.

10. The rising and setting of the moon, in all latitudes from the equator, is also affected by the obliquity of the horizon to the equator, and the obliquity increasing with the latitude of the place, the effect is also increased. The mean daily difference of the rising, southing and setting of the moon is 50 minutes and 28 seconds of time, but the true difference of southing varies from 40 to 68 minutes; and the rising and setting can differ no more or less at the equator, because the horizon there, as well as the meridian, is perpendicular to the equator; but in the latitude of New-York, on account of the obliquity of the horizon to the equator, added to all the other inequalities, the true difference of rising and setting varies from 20 to 80 minutes.

In many places at a great distance from the equator (either north or south) the obliquity of the horizon is so great that its inclination to the equator is even less than that of the moon's orbit. At those places the moon may sometimes be observed to rise or set earlier and earlier for a few successive nights or days, instead of later and later as with us. This phenomenon may sometimes be seen at Greenland, Davis's Straits, Hudson's Straits and the northern parts of Hudson's Bay, Slave Lake, Cook's Inlet, and all places on the globe at equal or greater distance from the equator.

We see then that the moon's motions and phenomena, although various as can well be conceived, are all fixed and certain; the effect of certain determinate motions and laws, without the knowledge of which no calculations whatever on the subject could possibly be made.

LECTURE THIRD.

An explanation of the Method by which the Magnitudes and Distances of the Sun and Planets have been determined.

SLOW and gradual was the progress of Astronomy in ancient times on account of their ignorance of the mathematics, and their want of mathematical instruments and tables. One improvement and one discovery must first be attained in order to prepare the way for another. It was long before any rational hypothesis was suggested.—Various were the opinions of philosophers, as is always the case with mankind while involved in the darkness of errour, prejudice and superstition; and while the subjects which agitate them remain mere matters of uncertainty and conjecture. Their opinions differed because they were nothing more than opinions. And when at length the true hypothesis was suggested, and adopted, a long course of observations was necessary in order to ascertain, with any degree of precision the motions of the planets, the inclinations of their orbits, the degree of their eccentricities, the situation of their nodes and aphelia; and especially to determine with any accuracy either the mean or the true motions of the moon. And after all, their opinions were various respecting the real distances and magnitudes of the sun, planets and stars; because these were subjects concerning which they had as yet no knowledge. The attainment of this knowledge, though not in the least degree necessary in order to calculate with the utmost precision all the phenomena of the visible heavens,* was nevertheless a very desirable object with them. It was not practicable, however, until calculations could be made with considerable accuracy. To shew that it is ultimately practicable is my object on the present occasion.

1. I shall in the first place show that the comparative distances of the planets were known before their real distances were, or could be, discovered.

2. I shall show in the second place how the magnitude of the earth has been determined.

3. How the distance and magnitude of the moon have been found shall be shown in the third place.

4. Fourthly, I shall show the method by which the distance of the earth from the sun has been ascertained, together with the magnitude of the sun.

5. In the fifth place I propose to show how the distances of all the planets from the sun, and their dimensions have been discovered.

6. Lastly, I shall make some observations respecting the magnitude and distance of the fixed stars.

I. The proportion which the distances of the several planets from the sun bear to each other was

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* *I mean here to except Solar and Lunar Eclipses, and all other phenomena of the moon. But the moon's true distance and magnitude were known before, and were discovered in the manner hereafter explained.*

known before their true distances were. Kepler discovered that the squares of their periodical times were to each other as the cubes of their distances. This law he might have discovered by the satellites of Jupiter or Saturn, the periods and distances of which could be determined by observation; I mean their distances, reckoned in semidiameters of their primary. The squares of their periods are in exact proportion to the cubes of their distances reckoned thus. Their distances bear the same proportion to each other reckoned in one measure, that they do reckoned in any other measure; so that if the distance of one of them were known in miles, the distances of the others in miles also might be found by the rule above stated. I wish to have it understood that this rule holds good throughout any certain set of planets. The square of the period and the cube of the distance of one secondary, are in the same proportion to each other, that those are of any other secondary revolving around the same primary, and not those of a secondary belonging to a different primary. A body of a different weight at the centre of the orbit will alter the proportion between the distance and velocity of the revolving body. If the sun were heavier than he is, the planets would need a swifter motion to balance his greater attraction. But with respect to the revolutions and distances of any distinct set of planets, either primary or secondary, the above proportion, or law, holds good. This law is observable among the satellites of Jupiter, Saturn and Herschel, and was demonstrated by Sir Isaac Newton. Now the periodical times of the planets being known by observation, their comparative distances may easily be computed by the foregoing rule. Any number may be assumed as the distance of a certain planet, and the distances of the others computed by it, according to the above rule, will be proportional. Thus, assuming for the earth's mean distance from the sun 100,000, we find the true relative mean distances of the primitive planets to be as follows, viz. Mercury 38,710, Venus 72,333, the Earth 100,000, Mars 152,411, Jupiter 519,958, Saturn 953,133, and Herschel 1,904,561.

The distance of a planet in any part of its orbit, in proportion to its mean distance, was also known before any thing radical was known respecting their distances. Thus if we assume 100,000 as the earth's mean distance, then her distance in her aphelion will be 101,692, and in her perihelium 98,308. The earth's relative distance, in any part of her orbit, was discovered by the apparent diameter of the sun, which varies from 31 minutes and 34 seconds to 32 minutes and 38 seconds. The earth's daily motion in her orbit, which is the same as the sun's apparent motion in the ecliptic, was found to vary from 57 minutes and 12 seconds to 61 minutes and 10 seconds. From these data it appeared by calculation that an imaginary line extending from the earth to the sun and carried round with the earth, would pass over, or describe, equal areas in equal times. This, by means of a variety of nice observations and calculations, was found to be an universal rule or law. This law was also discovered by Kepler and demonstrated by Newton. The mean motions of the planets were directly determined from the times of their revolutions; but to ascertain their true motions, in the various parts of their orbits, required a series of observations and some nice calculations which I have not time to describe. I wish to convince you however of the fact that their true motions were determined, and I think the following observation sufficient for this purpose. It is certainly a fact that they could precisely calculate the phenomena of the planets, their conjunctions, oppositions and other aspects, the times and even all the phenomena of transits ; but how could this be done without a knowledge of the true motions of the planets ? From a knowledge then of the true heliocentric motions of the planets in every part of their orbits, and a knowledge of the law just mentioned, they could easily determine the relative distances of the planets from the sun in all parts of their orbits.

II. I was next to show how the magnitude of the earth has been determined. This has been done by measuring a degree on the arc of a great circle, either the equator or some meridian, the limits of which had been determined by the stars. A degree was thus found to measure 69.5 English miles. This multiplied by 360, the number of degrees in a circle, gives 25,020 miles for the whole circumference of the earth. Then from the proportion between the circumference and diameter of a circle, we find the diameter of the earth to be 7964 miles, and its semidiameter 3982 miles.

III. In what manner the distance and magnitude of the moon have been discovered was to be shown in the third place.

1. If the real and apparent size of a celestial body be given, its true distance may be discovered by the following method, viz. as the tangent of half

the angle under which it appears, or the tangent of its apparent semidiameter, is to radius; so is its real semidiameter to its true distance. Now the semidiameter of the earth is given above, and its apparent semidiameter seen from the moon (which is called the moon's horizontal parallax) may be determined by the difference between the time when she appears to rise or set, and the time when she would appear to set or rise if she had no such parallax. This then will enable us to determine the earth's distance from the moon, which is the same as her distance from the earth. In this manner the moon's horizontal parallax has been found to be, when she is in apogee 54 minutes and 2 seconds, and when in perigee 61 minutes and 33 seconds, making her distance from the earth in the former case 253,325 miles, and in the latter 222,390 miles; and therefore her mean distance is 237,857.5 miles.

2. If the true distance and apparent semidiameter of a planet be given, the real semidiameter may be found in the following manner. As radius is to the tangent of the apparent semidiameter, so is the distance to the true semidiameter. The moon's apparent semidiameter when in apogee is found by observation to be 14 minutes and 45 seconds, and when in perigee 16 minutes and 48 seconds. In either case the true semidiameter turns out to be 1087 miles; so that the moon's diameter is 2174 miles. The content of the moon then, in cubic miles, is to that of the earth as 1 is to 49, and the area of her convex surface as 100 is to 1342.—This last is also the proportion which the light she affords the earth bears to what she receives from the earth.

IV. The fourth proposition was to show the possibility of determining the earth's distance from the sun, together with the sun's magnitude.

Were the sun's horizontal parallax known, his distance from the earth might be found in the same manner in which the moon's distance was; but the sun's horizontal parallax is so very small that every attempt to discover it in the way in which the moon's was discovered, has proved unsuccessful; some other method therefore must be resorted to in order to obtain his parallax.

When either of the inferiour planets makes a transit across the centre of the sun's disk seen from the earth's centre, the centre of its penumbra passes over the centre of the earth's disk seen from the sun's centre. I have premised that all the phenomena of the visible heavens may be calculated to as good advantage only by a knowledge of the comparative distances of the planets, which was previously known, as by a knowledge of their true distances. That line also, across the centre of the earth's disk, which an inferiour planet, seen from the sun, would appear to describe in a central transit, may be particularly determined, together with the latitude and longitude of those places through which it would pass. The apparent motion of an inferiour planet is always retrograde at the time of an inferiour conjunction; so that the motion of the planet on the sun's disk, and the motion of the penumbra on the earth, are always from east to west. An observer stationed near that point of the earth's surface which will be in the eastern boundary of her disk, and at one extremity of the forementioned line, when the penumbra's centre arrives there, will perceive all the phenomena of the transit a little earlier than one stationed in that place which will be in the western boundary of the disk at the other extremity of the line. This difference of time, whatever it might be found by observation, is the time in which the planet would traverse the earth's disk seen from the sun; and consequently the difference between the heliocentric motion of that planet and of the earth, for this interval of time, will be equal to the apparent diameter of the earth seen from the sun, or double the sun's horizontal parallax.

A transit of Venus is more convenient than one of Mercury, for this purpose, on account of her slower motion. The interval of time abovementioned will be of longer duration, and therefore the parallax determined with the greater precision.— For if the interval, as near as can be observed, should vary one second of time from the truth (as might reasonably be expected) when the whole interval is only one hundred seconds; then the parallax thus obtained might vary from the truth by the one hundredth part of itself; but the variation of one second in an interval of five hundred seconds, will occasion an error in the parallax of only the one five hundredth part of what it really is, and the distance to the sun obtained by it would vary from the truth at the rate of only one mile in five hundred miles. Thus a transit of Venus is more convenient for the purpose than one of Mercury.

When the centre of the penumbra is at any point on the earth's surface, the centres of the sun and the planet are in contact seen from that point; which circumstance cannot be determined so precisely as that of the first impression made by planet on the sun's disk, called the external cont or the beginning of ingress; or as that of its having wholly entered upon the disk, called the internal contact, or total ingress. It would be better therefore to station the observers in such places that one may observe the two contacts at the ingress from the eastern, and the other from the western boundary of the earth's disk seen from the sun at that time, and so that a straight line from one to the other shall pass over the centre of the disk. The observation of either the external or internal contact alone from both places would be sufficient, provided it should be exactly determined; but if both be observed it will amount to two experiments, and the mean result of the two may probably be more accurate than either alone; besides it is safer, for one contact might be visible at both places, and the other not, being obscured by flying clouds. It is highly proper also, in order to avoid disappointments as much as is possible and to heighten the probability of success, that the contacts at the egress should be observed by persons stationed in the same relative positions as were before described with respect to the ingress; for otherwise the accomplishment of the object in view would fail, if at either of the places the observations should be prevented by clouds.

The observers should set out for the places of their destination in due season, making large allowance for adverse winds and other casualties; and should arrive, with their assistants and their apparatus, some weeks previous to the transit, in order to have their clocks set and regulated with the utmost care and precision, and all other things in readiness.

If local circumstances render it inconvenient, it is not necessary that an observer should be precisely at the spot calculated upon. Fifty or an hundred, or even an hundred and fifty miles will not either essentially or perceptibly affect the result of the observation, provided that his situation be in the line which has been described; provided also that the one near the eastern boundary of the earth's disk be not so far east that the sun will set to him before the contacts take place, and the one near the western boundary, not so far west that the contacts take place before the sun rises. It will be his business however to determine precisely the longitude of the place where he makes his stand. This may be done either before the transit or after it, but it must of necessity be done in order to know the true difference of time between the meridians, without which the interval of absolute time which elapses between the appearance of a certain contact at one station and the appearance of the same contact at the other station, cannot be determined; which is the all-important object in this business.

I would observe further that whereas a central transit very seldom occurs, and perhaps seldom one so nearly central as that the centre of the penumbra comes at all upon the earth's disk, yet that a line across the centre of the disk, as before described, in a direction parallel with the line or path of the penumbra's centre, will in every respect answer the proposed purpose.

If all these things be punctually attended to in the time of a transit of Venus, the horizontal parallax of the sun, and consequently his distance, will be obtained to within a five hundredth part of what it really is; unless that Great and Good Being, who is superlatively so, see it best to prevent.

Suppose now that at the transit of Venus on the 6th of June, 1761, the interval of time which we have before so frequently alluded to was found to be 10 minutes and 45 seconds. The mean motion of Venus in her orbit for this interval, as you may easily calculate from the time of her revolution, is 43 seconds and 3 thirds, but as she was within about 53 degrees of her aphelion at that time, her true motion for the above interval was only 42 seconds and 41 thirds. The earth's mean motion for the same time is 26 seconds and 29 thirds, but being within 24 degrees of her aphelion at that time, her true motion was only 25 seconds and 41 thirds. The difference then between the true heliocentric motion of the earth and Venus for this interval was 17 seconds; the half of which, 8 seconds and 30 thirds, was the sun's horizontal parallax at that time, being less than its mean quantity, because the earth was so near her aphelion.—Now as the tangent of this parallax is to radius, so is the semidiameter of the earth (3982 miles) to its distance from the sun at that time, The result is 96,628,888 miles. It was well known before that the earth's distance from the sun in that point of her orbit was to her mean distance as 101,550 is to 100,000. Hence the mean distance appears to be 95,154,000 miles. This was very nearly the result of the observations made at that time. Mr. Short, who spared no pains to ascertain the mean result of all the observations which were made, I think stated it at 95,173,127 miles. There was another transit on the 3d of June, 1769, when the result of the observations was the same as before. The next will be on the 8th of December, 1874.

Now the sun's distance having been obtained, and his apparent semidiameter at any time being well known, his magnitude may be determined in the following manner. As radius is to the tangent of the sun's apparent semidiamter so is his distance to his true semidiameter. Therefore either take his mean distance, given above, and his mean apparent semidiameter, 16 minutes and 2 seconds; or his distance on the day of the transit, given also above, and his apparent semidiameter on that day, which was 15 minutes and 47 seconds. The result in either case makes the sun's true semidiameter 443,731 miles, so that his diameter is 887,462 miles. The sun then is as large as 1,383,748 of the earth, or as 68,025,625 of the moon.

V. I was to show in the fifth place how the distances of all the planets from the sun, and their magnitudes have been found.

1. The distances of the planets may be obtained from their comparative distances, mentioned in the former part of this lecture, by the rule of proportion. As 100,000, the earth's proportional distance there given, is to her true distance in miles; so are the proportional distances of the others to their real distances in miles. Or you may say, As the square of the earth's periodical revolution, is to the cube of her mean distance from the sun; so is the square of any other planet's period, to the cube of its mean distance. Thus the true mean distances of the primitive planets will be found to

be as follows. The mean distance of Mercury is 36,841,949 miles; that of Venus, 68,841,587; that of the earth (as mentioned before) 95,173,127; that of Mars, 145,054,515; that of Jupiter, 494,860,227; that of Saturn, 907,125,000; that of Herschel, 1,812,631,799 miles.

2. I come now to show how the magnitudes of the other primary planets were determined.

Their apparent diameters, or semidiameters, and their respective distances from the *earth*, are all the necessary data; these being obtained, work as before in finding the sun's magnitude. As radius is to the tangent of the planet's apparent semidiameter, so is its true distance from the *earth* to its real semidiameter. The apparent diameter must be taken by observation, and the true distance determined by calculation. As the distances of all the other planets from the earth, and consequently their apparent magnitudes, are subject to great and continual variation, it will be necessary to determine both these articles for the same period of time. The apparent diameter may be taken when there is a convenient opportunity, and afterwards the distance from the earth calculated for the same time. Find the distance of the earth, and of the planet whose magnitude is sought, from the sun, for the given time; together with the difference of their heliocentric longitude; then, by plane trigonometry, the distance of that planet from the earth may be found. But there are times peculiarly favourable for this business, when it may be done with greater accuracy and less trouble. The time of the opposition of a superiour planet is the best to take its apparent diameter; because, being nearer the earth, it appears larger, and we are not liable on that account to an error so great in proportion. It is the most convenient time also to determine the planet's distance from the earth, which at such times is always equal to the difference between the earth's distance from the sun and the planet's distance from it. With regard to an inferiour planet, the time of a transit is perhaps the most favourable of any to take its apparent diameter, and to determine its distance from the earth also, which at those times is likewise equal to the difference between its distance from the sun and the earth's distance.

Thus we see that the distance of any planet from the earth, as well as from the sun, at any time may be found; but with less inconvenience at particular times when its apparent diameter may be taken by observation to the best advantage; which two things are necessary in order to determine its real magnitude. The distance of Mars from the earth is more various than that of any other planet.— When in conjunction with the sun, and in aphelion, his distance from the earth is no less than 254,660,000 miles; but when in opposition, and in perihelium, it is no more than 35,400,000 miles. The angle under which his semidiameter is seen in the latter case is 15 seconds of a degree. Taking the last mentioned distance, with the apparent semidiameter at the same time, 15 seconds, we shall find by trigonometry, his real semidiameter to be 2575 miles, or his diameter 5150. In this manner the diameters of the planets were determined. Mercury is 3,222 miles in diameter; Venus, 7,690; the earth, 7,964; Mars, 5,150; Jupiter, 94,100; Saturn, 78,990; and Herschel, 35,226.

VI. The distances of the fixed stars were to be spoken of in the last place.

It is lawful to speak of things which are beyond our calculation or comprehension. We may speak of eternity and immensity, either of which is beyond the comprehension of Gabriel. The distance of the fixed stars we can never determine, yet it is not a subject which we know nothing about.

The greatest difference between the situation of a star seen from the earth, and its situation seen from the sun, may be called the annual parallax of that star. If this difference could be found, the distance of the star might be determined; for as the tangent of this parallax is to radius, so is the semidiameter of the earth's orbit to the distance of the star. But every attempt to discover the annual parallax of any, even the brightest, of the stars, which are therefore supposed to be nearest, has proved unsuccessful. A parallax cannot but exist, but the smallness of the angle renders it imperceptible. Astronomers have thought that if it amounted to one second of a degree, that is if the whole diameter of the earth's orbit appeared from the stars under an angle of two seconds, it would have been discovered; but to keep altogether within bounds I will suppose that the parallax might be sixty times as great in order to have been observed. I will suppose the semidiameter of the earth's orbit seen from the nearest star is less than one minute of a degree, because otherwise the parallax would have been perceived. Let us look at the distance on this supposition. As the tangent of 1 minute is to radius, so is 95,173,127 miles, or the semidiameter of the earth's orbit, to 327,200,000,000 miles. To fly this distance would take a body, moving at the rate of 480 miles an hour, 97,810 years. The nearest of the fixed stars is at least thus far distant from our system; how much farther than this, it is impossible for us to determine. We have reason to believe that this bears a very small proportion to the distance of those which shine so faintly in the cerulean fields, and that it dwindles into insignificancy in comparison with the distance of those millions, those innumerable multitudes, which the unassisted eye never can discover. The very appropriate exclamations of a celebrated poet, who flourished about one hundred years ago, force themselves upon my mind.

> "What involution! what extent! what swarms
> Of worlds that laugh at earth! immensely great;
> Immensely distant from each other's spheres!
> What then the wondrous space through which they roll?
> At once it quite ingulphs all human thought!
> 'Tis comprehension's absolute defeat!"

From the vast distance of the fixed stars, we conclude without hesitation and with absolute certainty that they are not opaque bodies, shining by the reflection of the solar rays, but that they are lucid bodies, emitting their own lustre. Such is their distance that our sun, great as it is, appears like a star and can no more supply them with light than they can furnish him. Such is their magnitude that they must be ranked with him in the order of creation, or they could never be discovered from such a distance. From these certain truth's and from analogy, it is rational to infer that they are suns, surrounded each by a set of planets and secondary planets which from their distance we can never actually discover. All these primary and secondary planets are doubtless the abodes of rational beings, as well as those of our own system.

Having travelled thus far in the unbounded regions of immensity, let us for a moment survey the galaxy. We find it to consist of systems in clusters; clusters involved and buried in clusters, in such profusion that a thousand systems would not be missed any more than a twig taken from a forest! And after all we have no adequate conceptions of the extent or the magnificence of the universe. Could we actually take our departure from this cluster of creation, and pass through that profundity of unoccupied space which surrounds it, and visit the most distant nebulæ which the telescope can discover; what should we still know of the Empire of the Infinite and ETERNAL SOVEREIGN! How vast are his dominions! How language fails in the description! Some borrowed expressions, though very inadequate, may better answer my purpose than any which I might frame.

"Is not this home creation, in the map
Of universal nature, as a speck?

. . . .

. . . .

May we not figure it an isle, almost
Too small for notice in the vast of being?
Sever'd by mighty seas of unbuilt space
From other realms; from ample continents?"

. . . .

. . . . Where?
Where ends this mighty building? Where begin
The suburbs of creation? Where the wall
Whose battlements look o'er into the vale
Of nonexistence, nothing's strange abode?
Say at what point of space Jehovah dropp'd

His slacken'd line and laid his balance by?
Weigh'd worlds and measur'd infinite no more?
Where rears his terminating pillar high
Its extramundane head, and says to gods,
In characters illustrious as the sun,
I stand the Plan's proud period: I pronounce
The Work accomplish'd; the Creation clos'd?"

LECTURE FOURTH

The Causes of the Ebbing and Flowing of the Sea explained; together with the Manner in which the Motion of Light was discovered; as also, the Consistency of the Motion of a Planet or Comet in an eccentric or elliptical Orbit.

IN the rapid progress which we have made in the preceding Lectures, several subjects worthy of attention have been passed by unnoticed. My design at present is to bring them under consideration; and I hope to bestow on them that attention which their importance may demand. I propose

First, to illustrate the causes of the ebbing and flowing of the sea;

In the second place, to explain the method by which the motion of Light has been discovered, and its velocity determined;

Thirdly, to show the consistency of the motion of a planet or comet in an eccentric or elliptical orbit.

I. An illustration of the causes of the ebbing and flowing of the sea, is the first proposition.

That this effect is produced by the influence of the moon is a rational conclusion, from the circumstance of its having, throughout all ages, precisely kept pace with the apparent daily revolution of that luminary.

But the grand queries, I apprehend, are, How is such an effect produced? and, Why are there two ebbs and two flows in one apparent revolution, whereas the earth has but one moon? The usual reply to these queries, and which is all I recollect to have read on the subject, is far from giving entire satisfaction. When we say, "the waters on the side of the earth next the moon are elevated by the moon's more powerful attraction, and those on the opposite side are elevated by her less powerful attraction," we leave the subject in the same obscurity in which we found it. A less degree of attraction cannot amount to a repulsion. In the sequel, it will appear that such an effect must be produced; and that there must be two ebbs and flows in one Lunar day, will appear with as much certainty as that there must be one. By a Lunar day, I mean the time from one southing of the moon to another, which is at a mean rate, 24 hours, 50 minutes, 28 seconds. I will,

In the first place, give a theory of the tides,

Secondly, apply it to the earth, and

Thirdly, answer objections that may arise.

I. A Theory of the Tides.

I have observed, perhaps once and again, that the time of a planet's revolution in its orbit, or its velocity, must bear a certain proportion to its distance from the sun; in order that the centrifugal, or projectile force, may exactly balance the sun's attraction, which is also called the centripetal force. This proportion has been found to be such that the square of the time of a planet's revolution round the sun, must increase or decrease with the cube of its distance from it. Thus, by calculation it will be found, that if a planet were situated twice as far from the sun as the earth is, the time of its revolution must be two years and 303 days; if three times the earth's distance, its period must be 5 years and 72 days; and if it were situated four times as far from the sun as the earth is, the time of its revolution must be just 8 years. Any certain velocity, then, or any certain periodical revolution, evidently requires a certain distance; and the distance of each planet is such as its velocity requires, or its velocity such as its distance requires.

If it were possible for a planet revolving in a perfect circle to be removed instantaneously to a greater distance from the sun, without affecting its velocity, it would immediately have a tendency to recede farther still from the sun; for its velocity, being too great to balance the sun's attraction, would carry it forward in a line of less curvature than that of a circle whose centre should be at the sun. Its orbit would therefore become eccentric; the place where the change of distance took place would be its perihelium; its mean distance would be greater than that to which it was removed, and its mean velocity less than before. The reverse of all this would take place on the supposition of its being removed nearer the sun without any alteration in its velocity. On account of the sun's too powerful attraction, it would fall within the compass of a circle; its orbit would become eccentric; the point where the change of distance took place would be its aphelion; its mean distance would be less, and its mean velocity greater than at that point, or than it was before. What I wish you particularly to notice here is, the tendency of the planet, on the former supposition, to recede farther from the sun on account of his weaker attraction, while the planet's velocity suffers no diminution; and its tendency, on the latter supposition, to approach nearer to the sun, on account of his greater attraction, the planet's velocity not being increased.

Now when we say the distance of a planet from the sun is such as its velocity requires, how do we wish to be understood? Certainly thus, that the centre of the planet is at such a distance from the sun's centre as its velocity or revolution requires.—Every part of a planet goes round the sun in the same time, but every part is not equally distant from the sun's centre. The side of a planet, therefore, nearest the sun has not sufficient velocity to balance the sun's attraction, which is more powerful there than at the centre of the planet. On the contrary, that part of a planet farthest from the sun, has too great velocity to balance the attraction of the sun, it being weaker there than at the planet's centre.

Let us now look at the effect of this disproportion between the distance of some parts of a planet's body, and their velocity.

1. The tendency of the nearest part of a planet to fall towards the sun, and of the farthest part to fly off from it, balance each other, so that the planet is retained in its orbit notwithstanding.

2. Suppose there were a planet, whose figure was a perfect sphere, consisting entirely of solid substances, that is, substances not fluid, which should revolve around the sun, and on its own axis, in the same period of time; thus keeping the same point at all times towards the sun. All bodies on its surface towards the sun would have less weight, on account of their tendency to fall to the sun; and those on the opposite side would be lighter, in con-

sequence of their tendency to fly off from the sun. The disproportion must be extremely great in order entirely to balance their gravity, or to overbalance it.

3. If this same supposed planet should revolve on its axis with greater velocity, the effect would be the same, except that those parts where the weight of bodies would be diminished, would be on different sides of the planet by turns, being always towards and from the sun.

4. Let us look at the effect of this same disproportion on a supposed planet entirely aqueous or fluid, revolving round the sun with the same point at all times towards him. The tendency of one side to fall towards the sun, and of the other to recede from it, would reduce its figure to an oblong spheroid, with its longest diameter directly towards and from the sun.

5. Let this aqueous planet be supposed to revolve with greater velocity on an axis perpendicular to the plane of its orbit, or not greatly inclined to it. This rotation would throw it into the form of an oblate spheroid. Yet its equatorial diameter would be longer in a certain direction than in any other, not perhaps in a direction to and from the sun. The revolution on its axis could not destroy the effect before spoken of, but the elevations of the fluid might be driven forward by it a certain distance, according to the velocity of its motion; in the same manner that a small swell of water on the under side of a grind-stone, when it is in motion, will be carried some small distance past the very lowest point of the surface of the stone, by its motion. A query must arise. Why is there not a

small swell of water also on the upper side of the stone? Answer. There would be, if the stone were supported from falling to the earth by a centrifugal force.

6. Suppose a terraqueous planet, like the earth, should keep the same points of its surface continually to and from the sun, throughout its annual revolution. The waters would be elevated on the sides towards the sun and opposite to him; but there would be no ebbing and flowing, because the two opposite protuberances would be stationary on the same points of the planet forever.

7. Let this terraqueous planet be caused to revolve, from west to east, on an axis not extremely inclined to the plane of its orbit. Immediately an ebbing and flowing of the waters will be perceived along the coasts of continents and islands; because different parts of the planet's surface will alternately be turned to those points where the waters are elevated, and also to those where they are depressed. These elevations or flows of the water will be carried forwards a certain distance, from the direction to and from the sun, by the revolution of the planet on its axis: and probably this distance will be much greater on a terraqueous than on an aqueous planet: but the flow and the ebb will both be perceived twice in every revolution, or, more precisely, twice in that period of time in which any point of its surface will be turned from the direction of the sun to the same direction again; which is always a little different from the time of a revolution on its axis, on account of its motion in its orbit in the mean time.

8. We will now suppose this planet to have a

secondary planet, or moon, revolving around it from west to east; performing several revolutions during one revolution of the primary round the sun. This secondary planet must also produce an ebb and flow in the waters of the primary, twice in the time in which the primary would turn a certain side from the secondary to it again; which would be a longer time than that in which it would turn from the sun to the sun again; because the secondary would make a greater advance in its orbit round the primary in that time than the primary would in its orbit round the sun. When the sun and secondary planet are either in conjunction or opposition seen from the primary, their effect on the waters will coincide; the flow will be higher and the ebb will be lower than would be caused by the single influence of either. On the contrary, when their apparent situation is ninety degrees asunder, the influence of one will destroy or diminish the effect of the other.

II. I shall now briefly apply the foregoing theory to the earth.

The earth revolves on her axis in such a period of time that any meridian is turned from the sun to the sun again in 24 hours; consequently there will be two flows and two ebbs of the sea in every such period, depending on the sun's influence. The earth turns any meridian from the moon to the moon again in 24 hours, 50 minutes and 28 seconds, at a mean rate, which period I have called a mean Lunar day; therefore two ebbs and flows of the sea, produced by the moon, will be perceived in every such period.

The Solar influence on the waters produces but little effect. Some have stated it at one fifth part of the effect produced by the influence of the moon; but I think this estimate too large. It is however perceptible in causing the Lunar flows and ebbs to run higher and lower about the full and change of the moon, when the influence of the sun and moon are united, and in the contrary effect at the quarters of the moon.

The attraction of the sun upon the earth is probably as great as that of the moon, and perhaps greater, but its effect on the waters cannot be in proportion to the strength of attraction. Attraction may be ever so powerful, yet, if all parts of the globe are equally attracted, there can be no such effect produced. Suppose the moon's centre were three semidiameters of the earth from the earth's centre, which would be one diameter of the earth from its surface. One side of the earth, on this supposition, would be twice as far from the moon as the other; and if the power of attraction decreased with the increase of the distance, the side of the earth next the moon would have double the attraction that the other side would. The diameter of the earth would bear so great a proportion to the distance of the moon, in this case, that it would occasion this difference of attraction. But suppose the moon to be sixty semidiameters of the earth from its centre; then the proportion which the earth's diameter would bear to the moon's distance would be much less, and the difference of the moon's attraction on the different sides of the earth consequently proportionably less. The sun's distance from the earth is 396 times as great as that of the moon, and on account of its vast distance it cannot attract one side of the earth much more powerfully than the other, because one side is but a very small proportion nearer to the sun than the other.

The power or influence of attraction does not merely decrease with the increase of the distance, but with the increase of the square of the distance. If then the centre of the moon were three semidiameters of the earth from the earth's centre, as we just now supposed, the degree of the moon's attraction on the nearest side of the earth, on her centre and on her farther side, would be in the proportion of 16, 9 and 4. By this we see that the tide on the side next the moon will be greater than that on the opposite side of the earth. The proportion on the present supposition would be as 7 is to 5, for the difference between 16 and 9 is 7, and the difference between 9 and 4 is 5. But a greater distance of the moon would leave a less difference of the tides. The difference at the moon's mean distance will scarcely be perceived, the proportion being as 121 is to 119.

III. It only remains on this subject, that I answer all the queries which I may be able to anticipate.

1. Why is there no tide in lakes and ponds?

Answer. There are no waters that can flow into them, without which the rise of the water will be imperceptibly small. Doubtless the surface of the water is more convex in lakes and ponds at the times when the moon passes the meridian both above and below the horizon, but this convexity can amount to but little in a few hundred miles.

2. Some have inquired why the rise or swell of the water is not perceived out at sea.

Answer. The swell takes place at sea, and might be perceived if the depth could be exactly sounded at the time of high and low water; but where sounding is impracticable the difference cannot be perceived.

3. Perhaps some may ask why there is no current in the ocean, as the waters rise and fall; as there is in the mouths of creeks and rivers.

Answer. Where waters are deep, but a small motion is necessary in order for such a swell to rise or to subside, because such a multitude of particles will move a little. If a spoonful of water be taken out of a pailful, no current will be produced in order to fill up the hollow which it occasioned. The hollow or cavity will be filled partly from the adjacent surface, but more by the rising of the water immediately below, which will be forced upwards by the weight of the surrounding waters. If in the middle of the Pacific Ocean, an aqueous segment of the terraqueous globe of an hundred feet depth in the centre should be taken off; although this would occasion no real concavity, yet there would be a kind of comparative concavity with respect to the convexity of the water level; so that if it could remain in this situation, although it would be a perfect plane of 24 miles, 4 furlongs and 20 poles in diameter, without the least concavity, yet it would be down hill, as we term it, from the circumference to the centre; but this hollow would immediately fill up without occasioning any perceptible current in the ocean. In the solid planet before supposed, whose figure was a perfect sphere, the disproportion between the attraction of the sun on its nearest and farthest parts, and the velocity of those parts, would have no visible effect; but it would occasion a something, like the hollow without concavity just spoken of (shall I call it a convex concavity?) on each side of the planet; and these two places would be directly to and from the sun, whether the planet were in motion or at rest on its axis, for where no effect is produced no time is required. If the planet were aqueous there would be a swell of water in each of these places; and if it revolved on its axis, the sinking of the waters in one place and their elevation in another would take place so gradually that no current or commotion could be perceived.

4. But here is another query. How can there be a tide on the side of the earth opposite the moon, seeing the earth does not move round the moon, and therefore can have no centrifugal force from it?

Answer. It is true that the earth does not move round the moon, but it moves round the centre of gravity of the earth and moon, which is not far from the surface of the earth, in a direct line extending from the centre of the earth to that of the moon. If the densities of the earth and the moon were equal, then this centre of gravity would be one forty-ninth part of the distance from the earth's centre in a direct line towards the centre of the moon. It is a point in this line where the two globes would be exactly poised. Now as the earth would acquire a centrifugal force from this point, it would be also from the moon, which is always in the same direction. One body can never stand still with another revolving round it; but both must move round their common centre of gravity. Such a motion is as necessary for the larger body as for the smaller one, and would originate if it were not originally given. Where a primary planet has several moons, as Jupiter, Saturn and Herschel have, it must in its own motion have respect to each of them, according to their distance and weight. This will cause its small motion round the centre of gravity to be very irregular, and also its tides. The same observation will also apply to the sun, surrounded by the primary planets, with respect to the irregularity of his motion around the centre of gravity of the system, and of the ebbings and flowings of his lucid atmosphere, or whatever it be (if fluid) which surrounds his body.

There are no other questions which I can at present conceive of, excepting those of a local nature, or such as arise from the effects of local circumstances, and have no concern in the general theory. Such is the inquiry which I have frequently heard respecting the remarkably high tides observed at the Bay of Fundy. There is no doubt but the true cause of this and other irregularities of a like nature might be discovered by a particular investigation of local circumstances.

Thus we have seen, in the course of this dissertation on the causes of the tides, that they are occasioned by a disproportion between the motion of the earth and the distance of some parts of it from the sun or the moon, the centre only being at the distance which its motion requires. We have seen that the centripetal force preponderates on the side of the earth next the sun or moon, on account of its proximity; and that there is a preponderance in favour of the centrifugal force on the opposite side of the earth, on account of its greater distance which would require a slower motion. We have seen that water, being fluid, will be affected by this disproportion, and become elevated on the two opposite sides of the earth, towards and from the moon or the sun; and that by the revolution of the earth on her axis, we meet both these elevations of the water, and the depressions which must necessarily occupy the intermedium, once in each Lunar day. We have seen then as clearly the reason of two ebbs and flows in a Lunar day as of one.

Before I dismiss this subject I would observe that the great irregularities in the motion and distance of the moon, together with the variations of the winds, and a variety of local circumstances, conspire to irregulate the tides, both with respect to their time and degree.

II. The method by which the motion of Light has been discovered, and its velocity determined, was to be explained.

The motion of light, and the velocity of it, have been discovered by the eclipses of the satellites or moons of Jupiter. The number of these satellites is four. The revolution of the first, or nearest to Jupiter, is performed in 1 day, 18 hours, 27 minutes and 33 seconds; that of the second, in 3 days, 13 hours, 13 minutes and 42 seconds; that of the third, in 7 days, 3 hours, 42 minutes and 33 seconds; and that of the fourth, or outermost, in 16 days, 16 hours, 32 minutes and 8 seconds. Their orbits are nearly circular, and therefore their motions nearly uniform. The orbits of the three first are so nearly in the plane of Jupiter's orbit that they fall into his shadow at every full and are eclipsed. The fourth is so far distant, and makes so great an angle with the plane of Jupiter's orbit that it does not fall into his shadow when the sun is more than sixty degrees from its nodes. There are generally about thirty eclipses in every month, counting those of all the satellites together. They are of use in determining the longitude of places on the land, and would be of great advantage at sea, if the irregular and violent motions of a ship did not prevent the observation of them.

In the calculation of these eclipses, after applying every equation which could possibly arise from the inequality of the motions of the respective moons, and of Jupiter, the calculated time would frequently differ several minutes from the observed time. Sometimes it would be too early, sometimes too late, and sometimes it would agree with observation. This difference could not arise from the motions of the satellites, because it was found to be the same at the same time with regard to every one of them. If at a certain time the eclipses of one satellite were found to take place either earlier or later than the calculated time, or to agree with calculation; the case would be found to be the same with respect to all the rest of the satellites. Besides all their eclipses were observed to take place before the calculated time in a certain part of their orbits, where at another time they took place after it.

But it was observed at length that their eclipses always took place earlier, with respect to the calculated time, when Jupiter was at or near his opposition to the sun, and later when he was near his conjunction with the sun. This circumstance made it evident that the difference was only occasioned by the motion of light. Jupiter is nearer the earth at the time of his opposition than at the time of his conjunction, by the whole diameter of the earth's orbit, or 190 million miles. In the former circumstance the eclipses were observed earlier because light, having less distance to travel, arrived sooner: in the latter case, light, having a greater distance to fly, the eclipses were consequently observed some minutes later. The greatest difference was found to be 8 minutes and 15 seconds earlier in one case, and so much later in the other; so that light travels 190 millions of miles in 16 minutes and 30 seconds, which is at the rate of 11,515,151 miles in one minute, or 191,919 miles in a second of time. This is 1,439,393 times the velocity of a cannon ball.

III. Before I conclude I must, according to what was proposed, show the consistency of the motion of a planet or comet in an eccentric or elliptical orbit.

The consistency of such a motion necessarily results from the combined effect of the laws of nature; which laws have been discovered, and by which we explain the phenomena of nature; but how or why those laws must necessarily exist can never be explained. No man can explain to us what gravitation is, any farther than that it is a tendency of bodies towards each other; or why the law of continued motion is, in the nature of things, necessary. Their necessity in order to prevent universal confusion is evident, and their existence any man may prove. Their effects are visible throughout the Solar system, as well as in all the scenes through which we pass on earth. These are the primary laws of nature. The former is generally called the centripetal force, and the latter the centrifugal force, when speaking of the motions of planets in the system.

From the combined effect of these primary laws, two secondary laws arise, which have been mentioned, and which are observable among the planets. Let us look at them again and see how far the province of each extends.

1. The squares of the periodical times of the different planets must be in the same proportion to each other as the cubes of their various distances are.

2. If a line be conceived to join a planet, or a comet, and the sun, and to be carried round the sun by the comet or planet; such a line will describe or pass over the same quantity of area, in a given time, in one part of the orbit as it will in another part; or in every part, like areas in like times.

The former of these laws does not extend to the regulation of a certain planet's motion in various parts of its orbit, or there would be no need of the latter; neither does the latter interfere in the adjustment of the mean motions of the various planets to their mean distances.

Although the former of these secondary laws requires that the velocity of a planet at a greater distance be less, yet it requires that the area described in a given time be greater; because a planet four times as far from the sun as another, must evidently describe sixteen times the area in one revolution, and has but eight times as long to perform a revolution in (as you will find by calculation) and therefore must describe double the area in a given time.

A planet then in its perihelium moves with greater velocity than a planet would that should revolve in a circle at the same distance from the sun, because it describes more area in a given time; the area described by a certain planet being always equal, whether it move in a circle or an ellipsis, and the quantity of area being greater with respect to a planet at a greater distance, or whose mean distance is greater. From a parity of argument also the velocity of a planet in its aphelion is less than that of one that should revolve in a circle at the same distance from the sun.

The planet Mercury in its perihelium is only 29,260,000 miles from the sun, in which circumstance its hourly motion is 15 minutes and 51 seconds. Now the centrifugal force, arising from so rapid a motion, overbalances the sun's attraction even at this small distance, because a planet revolving in a circle at this distance would only move 14 minutes and 27 seconds per hour. When Mercury is at his mean distance from the sun, which is 36,842,000 miles, his hourly motion is 10 minutes and 14 seconds, which would be the uniform motion of a planet revolving at the same distance from the sun in a circle. But when Mercury is in aphelion, his distance from the sun is 44,430,000 miles, and his hourly motion only 6 minutes and 53 seconds; whereas a planet revolving at the same distance in a circle would move 7 minutes and 43 seconds in an hour. His velocity therefore in his aphelion is not sufficient to balance the sun's attraction.

Thus it appears evident that the preponderance of the centrifugal force, when a planet is in its perihelium, will throw it off to its aphelion, from whence it will be drawn down again to its perihelium by the preponderance of gravity, or the sun's attraction.

It may not be thoroughly understood by every one, perhaps, how the motion of a planet becomes so much accelerated in one part of its orbit, and retarded in the other part of it. In order to make this a little more plain to the understanding, I would observe that if a planet should revolve about the sun in a true circle no such circumstance could take place; because the direction of the planet's motion in every part of the orbit would be perpendicular to that of the sun's attraction, which could therefore neither impel nor impede the planet in its progress. But the motion of a planet in an elliptical orbit is perpendicular to the sun's attraction only at its aphelion or perihelium. From aphelion to perihelium, the direction of its motion is a little inclining towards the sun, so that it will be continually accelerated by the sun's attraction; but in passing from perihelium to aphelion the direction of a planet's motion is just as much inclined from the sun, so that its velocity will be continually diminished by the sun's attraction.

Finally, if the distance and velocity of a planet, or comet, be precisely adjusted to each other, and at the same time the direction of its motion be perpendicular to the direction of the sun, it will forever revolve in a true circle with an uniform velocity; but if otherwise in any respect, it will revolve forever in an orbit more or less eccentric, in such a manner that its mean distance and mean motion will perfectly correspond. It cannot fall to the sun, because as it approaches towards him its centrifugal force will increase faster than the sun's attraction; neither can it be thrown off from him beyond a certain distance, because in receding from him its centrifugal force will decrease faster than the attraction of the sun, as has been abundantly proved from the forementioned laws. Thus then it will vibrate, between the two forces which act upon it, in a manner as natural and as comprehensible, if we were accustomed to it, as the vibration of a pendulum.

My exertions on this particular subject have been augmented in consequence of having understood that some persons were adopting the agency of electricity in order to explain the consistency of an eccentric motion; but as I have advanced nothing of mere opinion or conjecture on the subject; nothing but facts which admit of demonstration, I trust that all who have understood me are satisfied in this respect; for an explanation from such principles must afford satisfaction.

I would just observe further that this vibration of a planet up and down, with respect to its distance from the sun, cannot be the combined effect of gravity and electricity; because if it were, the mean distances of all the planets and comets from the sun would be the same. The eccentricities of their orbits might be various, but their mean distances would all be equal, being that distance at which the power of gravity and electricity would be balanced.

SUPPLEMENT.

CONCERNING THE DENSITY OF THE PLANETS.

HAVING said but little respecting the different densities of the various planets, in the course of the preceding lectures, I have allotted this subject a place here.

We believe all matter to be equally heavy, or alike subject to the power of gravitation, with respect to reciprocal attraction; so that when the difference of bodies with regard to bulk, does not correspond to their difference in weight; we conclude that they vary in density; that is, that one body contains more matter and another less, in any determinate bulk. Thus if a cubic inch of one kind of metal were as heavy as two cubic inches of another kind, we should conclude that the inch of the one contained as much matter as the two inches of the other; or that the density of the former metal was double that of the latter.

From this definition of the word density, it appears to be the quotient arising from the division of the weight of a body by its solid contents; and as the contents of globes are in exact proportion to the cubes of their diameters, the comparative density of a planet may be obtained by dividing its weight by the cube of its diameter. But we must come to the grand query, viz: In what manner are we to determine the weight of a planet?

This subject, although at first view apparently buried in darkness, is not involved in impenetrable obscurity. We have shown, in the foregoing lectures, that there is a certain proportion existing between the cubes of the distances of the primary planets and the squares of their respective revolutions; and, with regard to any set of secondary planets, or satellites, we have also shown that there is a certain proportion between the cubes of their distances and the squares of their periods. This proportion varies with regard to the satellites of different primary planets, on account of the different weight of the respective primary. It is the weight, therefore, of a planet which determines the proportion between the cubes of the distances of its satellites and the squares of their revolutions; and consequently this proportion must determine the weight of a planet. Therefore, to determine the weight of the sun, divide the cube of the distance of either of the primary planets, by the square of its revolution; and for the weight of a planet which has one or more satellites, divide, in like manner, the cube of the distance of the satellite, or either of them, by the square of its period. This will precisely determine the proportional weight of the sun, and of such primary planets as have satellites; which being respectively divided by the cubes of their diameters, will give their relative densities. The weight of a solitary planet can only be computed, or rather conjectured, from its effect in disturbing the motions of other planets. Perhaps it may be determined considerably near to the truth, by comparing its effect in this way, with that of a planet whose weight is known, and making due allowance for the difference of their relative situations. But the weight, and consequently the density of such planets, must remain rather uncertain, until physical astronomy is carried to greater perfection.

Concerning the Comets.

Comets are opaque bodies, moving through the heavens in extremely eccentric orbits. Their orbits are not situated all nearly in the same plane, like those of the planets, but are in almost every direction, and some of them move from east to west. By reason of the very great eccentricity of their orbits, they can only be seen when near their perihelia. Their periods are so long, and they are so seldom seen, that it is difficult to determine the elements of their orbits, so as to predict their returns. On their returns they may not always be recognized; for the earth may be in a very different part of her orbit, which may give the comet a very different appearance. Records are kept, however, of every appearance of a comet, and we know not at what degree of perfection this part of astronomy may hereafter arrive. The comet which appeared in 1531, is supposed to be the same which afterward appeared in 1607, 1682 and 1759, completing its period in about 76 years. It may therefore be expected to return again in the year 1834 or 1835. That of 1680 is the most remarkable of all the comets, and answers so well to the accounts of the one of 1105, that it is believed to be the same, completing its period in about 575 years. By a retrogression of seven periods, we find that one return of this comet was about the time of the flood.—

Whether that return was on the very year of the deluge, cannot now be determined, ancient chronology not being sufficiently precise, and the periods of comets also being liable to some variation.— Ridiculous as the opinion may seem, this comet is supposed by some to have occasioned that mighty inundation. The distance of this comet from the sun's centre, when in its perihelium, is about 500,000 miles; and when in its aphelion, it is about 13,161,500,000 miles. In the former case its velocity is nearly 800,000 miles an hour, and in the latter it is only about 30 miles.

A TABLE

Showing the Diameters, Distances and Densities of the Primitive Planets. The Densities of Mercury, Venus and Mars are more doubtful.

Names of Planets.	Diameters. E. Miles.	Distances. E. Miles.	Densities.
The SUN	887,462		25
MERCURY	3,222	36,841,949	204
VENUS	7,690	68,841,587	127
The EARTH	7,964	95,173,127	100
MARS	5,150	145,054,515	73
JUPITER	94,100	494,860,227	20
SATURN	78,990	907,125,000	11
HERSCHEL	35,226	1,812,631,799	22

TABLES

For Computing the TIME when the Stars come to the Meridian; and also when they Rise and Set.

TABLE I.

A CATALOGUE

Of the Names of the Principal Fixed Stars and of the Constellations in which they are situated, together with the time of their passing the Meridian, on the last day of December, the Third Year after Bissextile, and their Semidiurnal Arcs; fitted to Latitude 40 degrees and 43 minutes North, and 74 degrees and 15 minutes West Longitude from Greenwich; but will serve for New-Jersey and the adjacent parts of New-York and Pennsylvania, without essential Variation, throughout the present Century.

☞ *Mean Time, or such as is shown by a true Clock, is here reckoned; also the time of the Stars' coming to the Meridian is counted from Midnight.*

Stars of the First Magnitude.

Names of Stars.	*Constellations.*	*On Merid.* H. M. S.	*Arc.* H. M. S.
Aldebaran	Taurus	21 46 59	6 56 36
Altair	Aquila	13 4 47	6 28 10
Antares	Scorpio	9 41 46	4 19 54
Arcturus	Bootes	7 31 9	7 12 19
Betelguese	Orion	23 6 34	6 24 29
Capella	Auriga	22 24 42	9 57 50

TABLE I. *Continued.*

Names of Stars.	*Constellations.*	*On Merid.* H.	M.	S.	*Arc* H.	M.	S.
Castor	Gemini	0	47	56	8	10	20
Fomalhaut	Pisces	16	9	58	3	57	13
Procyon	Little Dog	0	54	39	6	18	37
Regulus	Leo	3	23	10	6	44	8
Rigel	Orion	22	27	8	5	29	50
Sirius	Great Dog	23	58	12	5	0	11
Spica	Virgo	6	39	34	5	23	23
Vega	Lyra	11	53	47	8	52	16

Stars of the Second Magnitude.

Names of Stars.	*Constellations.*	*On Merid.* H.	M.	S.	*Arc* H.	M.	S.
Algenib	Pegasus	17	26	2	6	49	13
Algol*	Perseus	20	18	7	9	5	43
Almaach	Andromeda	19	14	41	9	16	33
Alphard	Hydra	2	43	13	5	31	42
Alpheratz	Andromeda	17	21	11	7	48	11
Bellatrix	Orion	22	36	39	5	50	11
Benetnach	Ursa Major	7	4	11	Never sets.		
Deneb	Leo	5	3	58	6	54	20
Dubhe	Ursa Major	4	16	47	Never sets.		
Lesath	Scorpio	10	44	35	3	18	0
Markab	Pegasus	16	18	3	6	49	23
Menkar	Ceti	20	14	29	6	10	39
Mirach	Andromeda	18	21	37	8	24	49
Pole Star	Ursa Minor	18	18	38	Never sets.		
Pollux	Gemini	0	59	4	7	49	52
Scheat	Pegasus	16	17	18	7	43	20
Zubenelg	Libra	8	30	52	5	28	42
Zubenesh	Libra	8	4	33	5	4	44

* *This is a very variable star. It is sometimes no larger than one of the first magnitude.*

TABLE I. *Continued.*

Stars of the Third Magnitude.

Names of Stars.	*Constellations.*	*On Merid.* H.	M.	S.	*Arc.* H.	M.	S.
Acubens	Cancer	2	13	13	6	43	2
Albirco	Cygni	12	46	17	7	2	10
Alcyone	Pleiades	20	58	19	7	26	55
Alderaimin	Cephei	14	36	45	Never sets.		
Algorab	Corvi	5	30	35	4	59	55
Allioth	Ursa Major	6	10	0	Never sets.		
Kochab	Ursa Minor	8	14	50	Never sets.		
Rastaben	Draco	11	15	27	Never sets.		
Schedar	Cassiopeia	17	52	21	Never sets.		
Seginus	Bootes	7	48	28	8	56	0
Vindemiatrix	Virgo	6	17	7	6	40	46

TABLE II.

The Acceleration of the Stars for every Month throughout Four Years, commencing with Bissextile.

Bissextile.	H.	M.	S.	First after Bissextile.	H.	M.	S.
January	0	0	0	January	0	2	57
February	2	1	53	February	2	4	50
March	3	55	54	March	3	54	55
April	5	57	47	April	5	56	48
May	7	55	44	May	7	54	45
June	9	57	37	June	9	56	39
July	11	55	35	July	11	54	36
August	13	57	28	August	13	56	29
September	15	59	21	September	15	58	22
October	17	57	18	October	17	56	19
November	19	59	11	November	19	58	12
December	21	57	8	December	21	56	9

TABLE II. *Continued.*

Second after Bissextile.	H.	M.	S.	Third after Bissextile.	H.	M.	S.
January	0	1	58	January	0	0	59
February	2	3	51	February	2	2	52
March	3	53	56	March	3	52	57
April	5	55	49	April	5	54	50
May	7	53	46	May	7	52	48
June	9	55	40	June	9	54	41
July	11	53	37	July	11	52	38
August	13	55	30	August	13	54	31
September	15	57	23	September	15	56	24
October	17	55	20	October	17	54	21
November	19	57	13	November	19	56	14
December	21	55	10	December	21	54	11

TABLE III.

The Acceleration of the Stars for Days.

Days	H.	M.	S.	Days	H.	M.	S.	Days	H.	M.	S.
1	0	3	56	11	0	43	15	21	1	22	34
2	0	7	52	12	0	47	11	22	1	26	30
3	0	11	48	13	0	51	7	23	1	30	26
4	0	15	44	14	0	55	3	24	1	34	22
5	0	19	40	15	0	58	59	25	1	38	18
6	0	23	35	16	1	2	54	26	1	42	13
7	0	27	31	17	1	6	50	27	1	46	9
8	0	31	27	18	1	10	46	28	1	50	5
9	0	35	23	19	1	14	42	29	1	54	1
10	0	39	19	20	1	18	38	30	1	57	57

31 Days—2 H. 1 M. 53 S.

DIRECTIONS

For finding the time when the stars come to the meridian; or what is called their southing, if they pass south of the zenith.

1. Take out the time when they are on the meridian, given in table I.

2. Find whether the given year be Bissextile, or the first, second or third after it. This you may do by dividing the date by four; if nothing remain it is Bissextile, and the remainder, if any, will point out the year after Bissextile. With this and the month, take the acceleration out of table II. and subtract it from the former time.

3. With the day of the month, take the acceleration out of table III. and subtract it from the former remainder.

Note.—Borrow 24 hours whenever there shall be occasion; but if you borrow, in the course of the operation, remember to take out the acceleration for one day more than the given day of the month.

EXAMPLE.

What time will Alcyone (the brightest star in the Pleiades, or seven stars) south on the 19th of December, 1822?

	H.	M.	S.
Alcyone on Mer. from Table I.	20	58	19
Second after Bissextile, December,	21	55	10
	23	3	9
Having borrowed I say 20th day	1	18	38
	21	44	31
Throw off the forenoon hours,	12	00	00
Alcyone south in the evening, at	9	44	31

DIRECTIONS

For finding the rising and setting of Stars.

First find their time of southing, or coming to the meridian, as above; then, for the rising, subtract the Semidiurnal Arc, found in Table I. or add it to find the setting. *Note.*—If you borrow 24 hours in subtracting, you will have the time of rising the preceding day, and must yet subtract the acceleration for one day, in order to obtain the rising on the given day; or if, after adding, the hours exceed 24, you will have the time of setting on the following day, and must add the acceleration for one day, to bring it back to the given day.

EXAMPLE.

What time will Aldebaran set on the first day of February, 1833, which will be the first year after Bissextile?

	H.	M.	S.
Aldebaran on mer. from Table I.	21	46	59
First after Bissextile, February,	2	4	50
	19	42	9
First day of the month		3	56
Southing,	19	38	13
Semidiurnal Arc, add	6	56	36
Rejecting 24 hours,	2	34	49
Acceleration for one day, add		3	56
Sets in the morning, at	2	38	45

FINIS.